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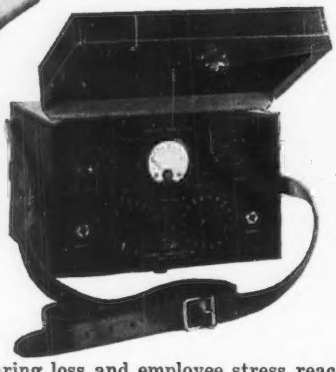

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Symposium on Threshold Limits

Present Trends in MAC's

Introduction by WARREN A. COOK, Associate Professor
Industrial Health and Hygiene, School of Public Health
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THE THINKING today on the concept of threshold limits of injurious materials, designated by whatever term, has passed through an evolution to a gratifying maturity.

Initially the need to know how little of a toxic substance might remain in an industrial atmosphere without injury to those exposed was insistently apparent. Such information began to be supplied through correlation of concentrations of injurious substances with observed effect on the health of the worker for such materials as granite dust[1] and lead compounds.[2] Results of short-time animal experiments had been available even before the present century from such investigators as K. B. Lehmann[3] and later from Yant and others at the U. S. Bureau of Mines,[4] with the classic combined long-exposure animal experimentation and occupational study on benzene by Greenburg[5] in the middle twenties.

As these threshold limit values became more numerous and were more widely applied, it is perhaps not surprising that misconceptions and aberrant usages occurred. Some persons erred in considering the levels more precise than the facts justified; others rejected them because the values could not precisely fit all conditions of exposure and physiological response. And the detractors were for a while more vociferous and seemed possibly to be more sound than the protagonists.

With time, there has been a separation of the valuable advantages of the threshold limits and the improper use of them. Nowhere is the present concept of threshold limits more ably and competently expressed than in the papers and discussions of this Symposium.

That the discussants might not have the very last word, it may be permissible for this prologue to assume in part the prerogative of an epilogue! The following commentaries appear pertinent.

The last publication of the American Standards Association Z-37 Committee on Maximum Acceptable Concentrations of Toxic Dusts and Gases[6] is reported correctly as 1949 by Sachs who deplored the lack of revision of the 1941 Standard for benzene at the obsolete level of 100 parts per million. It is to be noted that this ASA Committee is now active in the revision and publication of MAC Standards for many of the materials on which information is available.

The term "maximum acceptable concentrations" was adopted by the ASA Committee for a number of reasons. The word "acceptable" does not connote the legal control inherent in the words "allowable" and "limit," but rather a simple acceptability without further implication. Also, the expression, MAC, has been widely used over the years and is now a part of the language. In fact the Germans adopted a wording which gives the abbreviation, MAK, so that this term may be used in international conversation. Their words as used in the title of a paper by Oettel[7] are "Maximale Arbeitsplatz-Konzentration." It is understood that this same expression is being used in the "MAK" tables of the German Association for Worker Protection.

Presented at the Joint Session of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION—AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS at the 1955 Industrial Health Conference, Buffalo, April 26, 1955.

However, there can be no really valid objection to the term "Threshold Limits" used by the committee of the American Conference of Governmental Industrial Hygienists or to "Hygienic Guides," the term adopted by the American Industrial Hygiene Association committee. This Symposium would not be complete without reference to the availability of the excellent AIHA Hygienic Guides to which reference is made elsewhere in this Journal.

One of the most perplexing problems in arriving at threshold limits is posed by the cancerigens. Stokinger's statement in this Symposium is the first publication on this phase of the subject. However, the use of the procedure suggested by Stokinger as applied to nickel carbonyl has already drawn some fire. Quoting in part from a private communication from Oettel whose publications[7,8] on "MAK's" include a well-considered presentation of the general subject: "We suggest that consideration be given to indicating the suspected cancerigens with an asterisk with reference to a footnote that the hazard exists and consequently especially effective control measures be instituted. No man can say today which concentration of the several industrial substances is actually required to be cancerigenic . . ." This statement follows his objection to the present listing by the ACGIH of nickel carbonyl as 0.001 ppm on the basis of its alleged cancerigenicity, which incidentally Oettel's extensive experience with the substance causes him to doubt, while failing to include any acknowledgement of the known cancerigenicity of arsenic, chromates and asbestos. Says Oettel "In this I see a great danger. The lists should in any event remain logical."

Waters' discussion of Brandt's paper occupies the final pages of this publication of the Symposium, but it is believed that Waters would not wish his comments to be considered the last word on the subject of threshold limits—rather that his observations are limited essentially to the use of these values in legal codes, rigidly fixed by statute. As the last word in this Symposium, this introductory refers the reader to the concluding paragraphs of the paper by Brandt for his discussion of the philosophy of threshold limits.

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The Need for Threshold Limits

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Probably one of the most basic needs in human endeavor is for man to have an orderliness set to his manner of thinking. Everyone has a need for discipline, for boundaries to be drawn, and for limits to be defined. It does not matter that the only use for some of the limits so defined may be to ignore them; they have still served their purpose as a point of aim for individual interpretation. If this seems cryptic, an example concerning a common substance may be cited.

Almost everyone is familiar with the threshold limit values for silica—for dust with a free silicon dioxide content above 50%, the limit is given as five million parti-

cles per cubic foot of air (MPPCF), for dust with a free-silica content below 5%, the limit is 50 MPPCF, but 20 MPPCF is the value assigned for dusts with 5% to 50% free silica. It is rather difficult to understand how lungs could be so selective as to react with fibrosis if air containing more than 5 MPPCF of a 50% silica bearing dust was inhaled, but would be expected to remain healthy if a 40% silica content dust at the level of 20 MPPCF was similarly inhaled. It would be of doubtful accuracy for each industrial hygienist to interpolate on the curve of this wide range and apparent discrepancy. It has always seemed better practice to abandon the middle limits and when necessary forward a report (concerning dusts with a free-silica content of about 40%) that "dust with such a dangerously high content of free silica should be maintained in the working environment at less than 5 MPPCF." For agencies who have not conducted any research or original investigation along these lines, this might have been a precarious position under attack. Fortunately, the trend is toward revision of the limit for silica-bearing dusts.[1]

An Essential Tool

Actually, threshold limits satisfy the need for a tool essential to the protection of the health of the worker. The quantity of technical information concerning the biological actions of old and new chemicals is so vast that no single practitioner of industrial hygiene can be expected to be able to assimilate more than a very small fraction of this mass of material. A list of guide values prevents the chaos that would result if each investigator conducting plant surveys had to depend on his own comparatively restricted experiences and background. Two of industrial hygiene's sister specialities are admirable demonstrations of the benefits of having, and the disadvantages of not having, an approximate measurement of hazard. In radiological health and radiological safety the maximum permissible exposure value, blessed by national and international committees, has made possible much of the rapid adoption of various radiological techniques, uses of radioisotopes, and forays into the field of nuclear energy.

In air pollution investigation and control, lack of standards for permissible levels of atmospheric contaminants has seriously hampered wise administration of air pollution control practices, and has made it almost impossible to weigh the effects of these contaminants on the public health.

The need for threshold limit values *and the manner of use* is quite different for the staffs of governmental or official agencies and for persons employed by private industry or working with research laboratories, universities or foundations. Official industrial hygiene agencies must have a screening device to apply to literally thousands of industrial processes which are encountered in the day-to-day field work, from one year to the next. A screening device may very well be a single parameter but it should be used only for the purpose of suggesting more intensive and detailed study where the parameter is significantly exceeded. In multiphasic screening for chronic disease, the patient whose survey film is suspect for tuberculosis, cancer of the lung, or abnormal heart outline is referred to his private physician or to an appropriate clinic for more definitive diagnosis.

In discussing any screening test procedure, the question of false negatives versus false positives is certain to be reached. When the risk is permanent disability or death, the governmental industrial hygienist is so conditioned that he favors the side of the false positive; he tends to be too strict rather than too lenient.

For private industrial purposes, the threshold limit values satisfy the need for engineering bench marks. "Almost 100% confidence can be placed in the threshold limits where they are being used for evaluating and controlling of an industrial environment. This is particularly true in the use of these limits as a base line for calculating control design specifications in that the usual engineering factors of safety are included in such designs. It should be remembered that under this connotation the base line for comparison need not be extremely accurate. Naturally, the more accurate the figure is, the better economy that can be realized in engineering a control."[2] One of the deans of industrial hygiene and toxicology, restated this point of view as, "We need a yardstick even if it's only a rubber yardstick!"

Henry Smyth has given the most nearly complete description of the toxicological data required to satisfy all needs.[3] (1) What uniform concentration is tolerable eight hours a day for a working lifetime? (2) What correction in the average must be made for brief peak concentrations? (3) What single brief exposure to a high concentration is tolerable each day when there is no exposure the rest of the day? (4) What biological test upon the workman can measure his actual intake of the chemical at his job? (5) What are the earliest symptoms and objective signs of excessive exposure and how severe can they become before removal from exposure fails to prevent permanent injury? (6) What is the best treatment for the effects of excessive single exposure or excessive repeated exposure?" For a few industrial materials, all of these questions can be answered. The threshold limit values attempt to supply the answer only for question one. The introductory preface to the list advises caution in interpreting even this single answer. The introduction to the 1954 list has probably been well read. The preface to the 1948 list warrants repetition: "While it will doubtless be very advantageous to have what might be called permanent or standard maximum allowable concentration values, it must be borne in mind that all our values at the present time are fluid and subject to annual revision. They should not be adopted as fixed or legal values, but merely as guides to assist us in defining more or less safe working conditions. . . It must be borne in mind that these values are not indices of toxicity and are not intended to approach that value. Accordingly, the comparative toxicity of these compounds cannot be established on the basis of their numerical maximum allowable concentration value.

"People vary greatly in their response to drugs and toxic substances. Therefore, it is a figment of the imagination to think that we can set down a precise limit below which there is complete safety and immediately above which there may be a high percentage of cases of poisoning among those exposed.

"With these facts in mind the Committee has set values below which it is fair to expect reasonable protection and above which it is reasonable to expect that we can have occasional cases of poisoning."[4]

With so clear a statement of purpose on the books, it has always been somewhat baffling that several persons speak with bitterness and disdain about the threshold limits list. In all fairness, it must be admitted that the acrimony arises because the advice in the foregoing statement has frequently been disregarded and some regulatory agencies have not only allowed but have assisted the entrance of the threshold limits into the sacred and rigid precincts of the law. This is an unfortunate resting place for a scientific instrument that requires constant adjustment and calibration.

A number of excellent papers have been written on maximum allowable concentrations and threshold limits. In the interests of progress this panel discussion should be more than a review of bibliography. It should be a reflection of the opinions of the ACGIH-AIHA joint membership and some expression of their perspective on the threshold limits, their needs and their suggestions for changes or additions. Accordingly, a simple one-page questionnaire on the value of threshold limits was sent to the members of the American Industrial Hygiene Association and the American Conference of Governmental Industrial Hygienists (excluding those in foreign countries). A copy of the questionnaire appears on the next page.

Response to Inquiry

ONE THOUSAND AND FIFTY questionnaires were sent out, of which 340 were returned by the February 10 deadline. Fourteen of these were discarded since they were simply courtesy returns with the questions unanswered.

Of the 326 completed forms, the expressions of "confidence" in the Threshold Limits were divided as:

Confidence	Number of Replies
100%	53
80%	173
50%	37
Less than 50%	9
Qualified	54
Total	326

The group of *qualified* answers were essentially those who wrote they could not apply a numerical rating to their reactions to the threshold limit values or who said they

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THE NEED FOR THRESHOLD LIMITS

(1) How would you rate your confidence in the ACGIH Threshold Limits? (check one)
100%___ 80%___ 50%___
Less than 50%___

(2) Do you think we *need* a list of Threshold Limits? Yes___ No___

(3) What standards of performance would you prefer?

(4) When you use or instruct as to the use of Threshold Limits, what qualifications or reservations (if any) do you advise?

(5) Other Comments

(6) May I quote you by name? Yes___ No___

Name_____
Title_____
Affiliation_____

had, for example, 100% confidence in some of the values and little or no confidence in other values, particularly values for some newer substances assigned because of chemical or structural similarity to a material with a well-documented value. At this point it should be emphasized that many, many responses were careful to explain that their confidence rating was for the "value"; that their confidence in the Committee on Threshold Limits was unqualified.

The question, "Do you think we *need* Threshold Limits?" was answered

Yes	323
No	3
Total	326

In the qualified answers, in the comments and in the suggestions for other standards of performance, there were many pleas for regrouping of data and for additional information. These were expressed in many different ways but lent themselves to a few major headings. There were 103 requests that the list indicate whether the value was an "injury" value or a "nuisance" or "comfort" value; there were 73 requests for a notation as to whether the value was based on animal experimentation or human experience; 75 persons desired a short exposure value, a one-hour tolerance or a value for "peaks"; 32 wanted information on multiple exposures, synergism or additive effects; and 28 thought the references should be printed along with the assigned value.

These suggestions may be summarized as follows:

Requests for	Number	
Comfort threshold (nuisance level)	61	103
Chronic toxicity threshold (injury level)	42	
Animal experimentation or human data	73	
Short exposure threshold, one hour, peaks	75	
Synergism, multiple or additive exposures	32	
References on list	28	

Several of these comments and requests were embodied in enclosed reprints, long letters and telephone calls. With all this active and militant thinking, there should be no great fear that threshold limits will be applied blindly or that a numerical value will ever entirely replace thoughtful, scientific appraisal of the many factors that must be considered concerning the health of the worker and the status of the workroom environment. Especially, the need for medical examination and a determination of the general physical condition of the worker seem well understood.

What to be Expected of ACGIH List

ONE pertinent question remains to be answered. What can logically be expected of a list, revised annually, compiled by a committee, each member of which is earning his living at a full-time job? One of the major values of the list is that it is revised annually, and new substances added as data are forthcoming. The excellent Z37 series prepared by the American Standards Association contains much more information than appears on the Threshold Limits list. However, of the toxic dusts and gases group there have appeared 15 leaflets, the most recent of which was entitled, "The Allowable Concentration of Methyl Chloride" which was published January 5, 1949. "The Allowable Concentration of Benzene" was

approved and published January 15, 1941 and states the permissible concentration as 100 parts per million parts of air by volume. So far as is generally known no revisions of this ASA figure have appeared although it is commonly agreed that the 1954 ACGIH value of 35 parts per million is a far safer working figure and one that is practical.

If it would not unduly burden the Committee on Threshold Limits it would be advantageous to have a regrouping of the listed values according to comfort thresholds and chronic toxicity thresholds. And where they exist and are easily verified, it would be most helpful to have a special group of one-hour tolerances or peak short-time permissible exposures. The combined membership of today's audience might give consideration to the publication of a monograph on threshold limits which could very well be a compilation of fundamentally sound material which has already been published. The monograph could include the papers already referred to in this article, with perhaps several others that are equally well known.[5,6,7,8]

No list of values and no amount of regrouping and no increase in the number of background references can relieve the industrial hygienist of the responsibility of acquiring sufficient education and training to do his job properly and to think for himself. It seems desirable to add here another reference, "Education in Radiation Protection,"[9] the Janeway lecture delivered by Lauriston S. Taylor. The words spoken by Mr. Taylor while directed particularly to the field of radiation exposure apply just as well to any industrial chemical exposure. He states:

"The young radiologist should be educated in the background and significance of permissible dosage or exposures and should at all times retain a sense of proportion and a sense of humor relative thereto. For example, the present permissible exposure for the whole body is 300 milliroentgens per week (measured in air). This figure was determined from a limited amount of clinical and biological data to which was applied a series of well educated guesses, and yet we may find a person's weekly exposure recorded as, say 163 milliroentgens—a figure that few, if any, practical clinical instruments can measure with an accuracy of better than ± 10%. Again, if a film badge (accuracy ± 20%) shows a reading of 260 milliroentgens for one week, are we to be alarmed? And are we to be complacent with a duplicate reading of 200 milliroentgens taken in the same place for the same week? Actually both readings are the same within experimental limits of error and we should be alarmed in both cases not primarily because the readings differ but because the exposure in each situation may be unnecessarily high. It is only rarely that working conditions at a radiation level far below the permissible dosage cannot be obtained with but little inconvenience or added expense.

"The aim should be to see how low a practical operating level can be achieved—not how high a level without transgressing the 300 mr per week medicolegal upper limits set by radiation safety experts. Even the smallest amount of radiation has some effect on the living human body. Even if the harm is normally undetectable by the individual, genetic damage can result from single minute exposures. We must prevent perceptible harm or damage—we should minimize the likelihood of undetectable damage even though we cannot eliminate it entirely."

The fundamental goal should be the improvement of industrial hygiene practice. Threshold Limits, however accurate, and however well-documented, serve only as a guide and a yardstick. No method ever has been, or ever can be, devised that will permit an exact advance prediction of human hazard. The closest we can come is human judgment.

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Prepared Discussion

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DR. SACHS has established that the vast majority of our colleagues recognize their need for a list of threshold limits. She distinguishes between the need of the official agencies for a screening device to apply to thousands of industrial processes they encounter in field work, and the need of the private industrial hygienist for an engineering bench mark for planning and evaluating environmental control. To satisfy each of these needs vapor concentrations must be measured under operating conditions before the threshold limits values can be useful.

There is a third group which uses threshold limits and needs them because nothing better suited to the need is available. Every one of our profession is a part-time member of this group and some are full-time members. Reference is made to the arm-chair industrial hygienist. He may never measure a concentration and he may never observe an industrial operation. He uses threshold limits to advise upon the selection of a chemical for a particular application, to select a suitable application for a little known chemical and to bolster sales arguments for a chemical or mixture of chemicals.

When the industrial hygienist is asked to advise whether acetone, propyl acetate, or methylene chloride would be the safest solvent in a particular application, it may be believed that his answer is based on a profound knowledge of toxicology, but actually he recalls the threshold limits, or refreshes his memory by consulting the list while the questioner waits on the telephone. Then the answer is given as if the list recorded comparative toxicities, perhaps adding a bit of qualitative information on fire hazard and type of injury from an excess.

What better data are available for the arm-chair industrial hygienist than the annual list of threshold limits? He must have some guidance if he is to do more than toss a coin. If he is given a list based on uniformly conducted animal experiment, he is deprived of the benefit of the years of carefully observed and evaluated human experience which is recorded in some of the threshold limit values. Whether we want him to or not, he (and that includes every one of us at times) will use threshold limits as estimates of comparative toxicity to meet his urgent requirement for finding some basis for opinion.

To what extent is he wrong? A threshold limit based on comfort, irritation or good engineering practices certainly is not comparable to one based on pathological effect. But the former limit is certainly lower than one based on injury. The error is on the side of safety if it is stated that material A has a threshold limit based on comfort higher than that of material B which is based on injury, therefore material A should be used in the process.

No matter which material is chosen it will be employed by persons subjected to the same degree of industrial hygiene and medical scrutiny. By choosing the material with the higher threshold limit the probability of safe operation has been increased, even if the basis on which the choice was made is not numerically sound.

There is one important short-coming in this argument which points out an important way in which threshold limits do not meet the needs of the arm-chair industrial hygienist. If the volatility of a material with a high threshold limit is greater than that of a material with a low limit, then in a particular process the less toxic material may be more hazardous, because a greater vapor concentration will be in the atmosphere.

I maintain that the list of threshold limits is our best available source for judgments on comparative toxicity of vapors to humans. It can be improved for this purpose, but there is nothing better for us to use. However, it refers to toxicity, not to hazard. It is the single-phased toxicity of K. B. Lehmann. A table of comparative hazards would go back to Lehmann's two-phased toxicity by combining vapor pressure (or evaporation rate) with toxicity. This table of comparative hazards is what the arm-chair industrial hygienist really needs. It would go a long way toward satisfying all of his needs, particularly if it included information on nature of injury, on the penalty for exceeding the limit and on the degree of hygienic urgency for observing the limit.

Methods of Establishing Threshold Limits

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THRESHOLD LIMITS are based upon information derived from many and diverse sources. For each evaluation, data developed by many different methods may need to be considered and weighed; and from this sometimes complicated, often contradictory, and rarely adequate, complex of information, a significant value must be developed.

It is customary to append, as reference material, the important published studies from which the conclusions were made. In these studies, particularly if the author felt that his contribution permitted such a judgment, there is often a proposed threshold limit value. Not infrequently, of course, the values suggested by different investigators may disagree. The group which is charged with the responsibility for establishing threshold limits must consider, in addition to the character of the study, such qualities as accuracy, reliability, completeness, and purpose—and, a not insignificant factor, the reputation of the investigator.

The subject, "Methods of Establishing Threshold Limits," has a connotation beyond that of the procedures and techniques reported in the industrial hygiene literature. This has to do with the actual mechanism by which a group or a committee is designated to act as a body for establishing threshold limits, and the principles and practices which actually govern the operation of the committee. In the present evolutionary stage of industrial hygiene, the internal activities of this committee must weigh heavily in any consideration of "methods."

Threshold Criteria

IT WOULD BE worthwhile, if it were possible, to record all of the elements of a deliberation in arriving at a standard. Often, there is considerable material, undocumented, which plays an important role in the evaluation, in addition to the published studies. This may be limited and fragmentary data from industrial or governmental industrial hygiene surveys; or it may be incomplete data from animal experiments; or reports of cases of alleged intoxication from Workmen's Compensation sources.

A still less tangible factor, related to the experience, training, and critical judgment of the individuals performing the evaluation, is the ability to make a variety of extrapolations. In one instance this may involve the estimation of the probable effect in man from data developed in one or more species of lower animals. The experimental toxicology data may be limited to acute or subacute experiments; but even if chronic, long-term studies have been done, the translation from a few years exposure, even though a lifetime for the animal, to the long span of a working lifetime in man is a difficult step. In other cases, the extrapolation may be from experimental or clinical data developed with one chemical to the probable effect of an homologous compound or a material with similar chemical structure.

The behavior of a substance in other fields —as a therapeutic agent, an insecticide, or even as a beverage (as in the case of ethyl alcohol) may contribute important information. The background of the individuals making the judgment, with respect to personal experience ranging from animal experimentation through long-term clinical observation of exposed workmen, with respect to a practical and critical appreciation of the value and limitations of methods for making environmental measurements, determines the ultimate value with which all of these factors, concrete and abstract, are blended to form a valid, practical, and acceptable threshold limit. The more substantial the documented information, the broader the sources of pertinent data, the less the demand for these intangible factors to fill the gaps which are inherent in this kind of procedure.

The absolute test of a threshold limit has

not been, and probably will not be achieved if the measure of validity is strictly construed in terms of a completely "safe and healthful" environment for the occupational lifetime of an individual. Practically, criteria much less complete are accepted, although the trend is to the constant improvement of our methods for evaluating long-term and more subtle effects. These more remote parameters of injury are seen in the extreme in the study of radiation effects, where consideration is given to such factors as shortening of the total life span, and of genetic effects involving future generations. With the great majority of physical and chemical agents, we must be content with threshold limits predicated upon less extensive and less subtle end-points.

If threshold limits, even with their present imperfections, are accepted as useful and desirable, they must continue to be fabricated from information which is sometimes inaccurate, frequently controversial, and always incomplete. In this discussion, no attempt will be made to define a pattern of acceptability for the various elements of evidence which may be considered in establishing threshold limits (this might be paraphrased as "threshold criteria" for threshold limits). This will vary with the purpose for which the limits are intended, the character of the group making the judgment, and the need for such standards. At this point, it might be suggested that the various bodies which are responsible for establishing standards, attempt to define in general the purposes, criteria for acceptability, and limitations of their function—and perhaps, specifically indicate the basis for their judgment in individual instances where important factors other than the appended reports played a significant part. The publication of this information would not, of course, still all criticism, but it would obviate much of the criticism which is based upon unfamiliarity with the manner in which a decision is made. It is paradoxical, that the greater the need for a threshold limit (in terms of the numbers of individuals actually being exposed, and the severity of exposure) the greater the justification for accepting a tentative standard on inadequate and incomplete information. This practice is defensible, of course, only if this initial guiding limit is continuously and critically tested by a competent clinical study of the exposed people.

Sources of Information

THE TWO GENERAL sources from which significant information is developed are the experimental laboratory where the exposure is deliberate, and the actual plant operation, where the exposure is incidental (sometimes accidental). The establishing of threshold limits depends increasingly upon a balance of information developed from both these areas. The more complete the laboratory investigation, the greater the security of the tentative standard for plant exposures. The inherent uncertainty of extrapolation from the experimental data necessarily places the final judgment upon the clinical evaluation of the exposed workmen.

Industrial hygiene laboratory methods run a gamut from the simple, preliminary "screening" procedure using a few small animals to a relatively involved, carefully controlled, clinical experiment in which human subjects are deliberately exposed to a toxic agent. The studies with lower species should define a range from minimal or no effect through severe injury and lethality, and should indicate the various physiological and pathological mechanisms of injury. The exposure levels for the human subjects usually attempt to define levels associated with "discomfort," "minimal," and "earliest reversible" effects.

There is no formula at present by which it is possible to estimate the pattern or amount of laboratory experimentation which will be required of this component in establishing a threshold limit. In general, the more novel the physico-chemical properties of the agent, the more distantly related to other materials which have had industrial hygiene evaluation, the greater the amount and variety of toxicological procedures which must be employed. The direction and extent of further studies must be determined as the pattern of toxicological investigation unfolds. The importance of the various routes of absorption, the relationship of divided dose administration to the single effective dose, the relative primary irritation and sensitization potencies, the behavior in relation to such factors as species of test animal, age, sex, concurrent disease, are only a few of the important items which

must be considered in deciding the importance of the role which a particular animal study may play.

Some of the experimental toxicological findings which suggest caution in evaluating a study may be noted. A lethal dose curve whose slope is gradual may overlap the curve of the physiological function upon which the threshold is to be based. A scattered configuration of delayed deaths suggests multiple effects or secondary pathology which may be difficult to evaluate. A substance which is a sensitizer or allergen, even though indicated solely by skin sensitization tests, may produce systemic or specific internal organ sensitization. Marked variance with respect to severe injury or lethality among several species of test animals, increases the difficulty of extrapolation. The failure to reproduce the disease pattern already identified in human subjects definitely limits the significance of animal studies. Less clearly identified effects, such as involvement of the central nervous system, or injury which is not easily reversible, such as aplastic anemia, signal caution.

Experimental methods with deliberate exposure of human subjects to low levels of a toxic agent are finding increasing usefulness in establishing threshold limits. Initially, many of these tests were concerned with irritation or discomfort levels, and although no injurious effects were noted in animals exposed to higher concentrations, the human experiment values were frequently the determining factor in setting a threshold limit. A possible fallacy in this reasoning lies in the quite common experience of finding conditions in plant operations which are quite irritating or uncomfortable to a person first entering the environment but which are tolerated without complaint—or even, in some cases, with a positive expression of benefit—by the acclimated workmen. In such an instance it is difficult to decide which result is significant, the controlled short-term study using, usually, subjects whose experience with industrial conditions may be very limited, or the testimonial evidence of workmen, especially if unsupported by evidence which confirms the absence of injurious effects.

Other applications of the controlled human-subject experiments may develop more important information. The studies of retention of a toxin (with the long-term investigations of lead and fluorine as classic examples) must play an important role in the establishment of threshold limits for these substances. The obvious advantage in this technique lies in the accuracy with which the relation can be established, as contrasted with the more difficultly controlled experience in the plant. More of these studies on a long-term basis are needed, but the cost in effort and in dollars imposes distinct limitations.

This type of experimental approach is of value in determining the earliest (and still reversible) changes in certain physiologic functions, such as vascular instability as measured by blood pressure changes, or metabolite excretion, as in the urine sulfate partition with benzol absorption. The objective, of course, is to recognize a reversible, functional change which, if unchecked, may lead to permanent injury. A practical difficulty may develop as the acuity of test procedures increases, since the changes frequently are not specific for the toxin but may occur with many other factors which affect the body—as for example, an excess of alcohol. On the other hand, special application of statistical methods to group exposures may make these techniques one of the most acute methods of signaling injury.

Value of Data on Worker Exposures

THE CONCEPT that a careful and comprehensive study of the exposed workmen is the most significant factor in establishing a threshold limit, merits repetition. In practice, however, the number of substances for which such complete studies have been reported are few. A number of factors operate against such long-term, comprehensive investigations. The cost of an adequate clinical program, carried on over many years and with continuing negative results, requires the support of an unusually intelligent and understanding management. The development of environmental measurements so as to be effective for correlation with the clinical findings requires a high degree of cooperation and planning between clinical and industrial hygiene activities. And, finally, the job of organizing the extensive data, of deciding that the results are significant, particularly if they are negative in the sense that no injury is found, and

of preparing for publication (since there is no Journal of Negative Data), demands of an investigator courage to the point of being foolhardy.

Of the various types of information which can be obtained from actual industrial exposures, the unsupported testimony of workmen and supervisors, even though accompanied by accurate measurements of environmental factors, is generally so unreliable as to merit little weight in establishing a threshold limit. Individuals who are unable to tolerate the work conditions, or those who have actually become ill and left the job, may have been eliminated so gradually that recognition of the cause and effect relationship may not have developed in the remaining personnel. Furthermore, human nature is such that under these circumstances the men remaining on the job are apt to dismiss the others who left as being "too weak to take it."

As in the case of planning a program of experimental laboratory methods for evaluating a toxic agent, the in-plant clinical survey and environmental analysis must develop in relation to the specific hazard. To the basic elements in the medical examination may be added a variety of special test procedures selected to detect the earliest changes in physiologic function. If little is known about the kind of toxic reaction which may develop, a "shot-gun" approach may be justified with the hope that one or more of the battery of tests will signal a harmful effect. As knowledge of the earliest reactions to specific agents increases, the selection of the most sensitive test procedures becomes more practical, and more reassuring.

The recognition of an occupational disease is frequently much simpler than the proof that a particular exposure is free from any injurious effect. As exposures to toxic materials are decreased from levels which can injure in a relatively short time, a point is reached where the signs and symptoms may develop only after a very long exposure time, and the disease so mild as to challenge the best diagnostic program. We can note again the studies with radiation, where minimal shortening of the life span with relatively low exposures can be demonstrated in experimental animals but would be impossible to detect, with our present techniques, in the human subject.

Clinical Observations

THE BROADER the base of the clinical investigation which is associated with a finding of no injury or no significant injury at a particular exposure level, the greater the reliability of the conclusion. To the critical investigator, however, the job is never complete, never without some area in the study which could not have been strengthened or improved. The period of the study can extend into many years, and yet the end point can remain uncertain.

As other techniques are added to the evaluation program—such as studies of morbidity and absenteeism, reasons for dispensary visits, and analysis of cause of death—the problem of interpretation becomes increasingly complicated. An example may be cited in which two young women employees in the same small department developed leukemia within a few months of each other. This occurrence was readily accepted as a chance finding because both girls had clerical positions with no possible exposure to an industrial toxin. Had this occurred following a common exposure, however brief or minor, to a new chemical with a long and unfamiliar name, it is quite likely that medical testimony would have been developed, in a Workmen's Compensation hearing, attributing the disease to the exposure. The effect of the incident might well have extended beyond the cost of compensation and into the area of threshold limits by the publication of a case report. A fine discretion is required in recognizing the first or isolated instances of injury to a new chemical and yet avoiding the inclusion of cases solely on legal or social motivation.

In a study of the long-term effects of a solvent, records were kept of the causes for dispensary visits. A slightly higher incidence of gastrointestinal complaints was found in the exposed group, and since this had been reported previously by others, it seemed significant. However, the incidence of respiratory complaints was as much lower for the exposed individuals. In an interpretation, it would have been equally proper to assume that the solvent vapors "protected" the individuals against respiratory disease, and that this beneficial effect might offset the gastrointestinal difficulties. As might be suspected, when these relations were put to the test of statistical signifi-

cance, both could have been due easily to chance alone.

A final word is in order concerning the methods for developing data by which the environment is described—the conditions of exposure. As much variability can be, and is, encountered with this function as with the methods for laboratory experimentation and in-plant clinical examinations. The accuracy and reliability of the analytical techniques, the relation of the time and site of sampling to the true exposure, the presence of other agents which might modify the single action of the toxin under study are some of the many factors which must be critically examined in the light of their usefulness for correlation with a given set of experimental or clinical findings.

It is obvious that there is no single method or pattern of methods which can satisfy the varied requirements for establishing threshold limits. It is equally obvious that even though rigid standards were described which would satisfy a discriminating jury of scientists, the available data for establishing threshold limits for all but a very few substances would fail to satisfy such limits. The real use for threshold limits, as a guide for industry in the control of exposures and as a measure for action by governmental agencies, demands a continuing improvement in the quality and quantity of the methods by which truly valid criteria may be achieved.

Prepared Discussion

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DR. STERNER has discussed the great difficulties attendant on developing adequate data for threshold limits, the many imponderables in their interpretation, and their unsatisfactory and necessarily always incomplete nature. All these considerations should certainly be thoughtfully considered and strongly stressed, because errors in judgment cannot be afforded. But lest these many considerations seem so formidable to many potential investigators as to prevent their needed contributions (which was far from Dr. Sterner's intention) or depress the more experienced contributors, it should be immediately pointed out that there are at least two practical and very helpful means of overcoming certain deficiencies inherent in the basic data. One is the safety factor, the other, the periodic re-evaluation of the threshold limit values. The safety factor has been built into most of the values in the threshold limits list.* The factors 2, 5, 10 or even greater have been applied to some values. There are, of course, some notable exceptions, such as the present value for trichloroethylene, for which the threshold limit is the absolute ceiling, but generally such instances are rare. In general, the greater the uncertainty in the data's applicability to human industrial exposure, the larger the factor applied. This lowering of the limit value by an arbitrary safety factor may at times provoke some controversy, because now the value becomes one of opinion, not fact. Be that as it may, the safety factor incorporated in the air standards gives increased assurance of safety to many doubtful values.

The re-examination of the listed values by the committee provides annually for readjustment of all values, whatever their sanctity, upon submission to the committee of new and experimentally supported findings. Repeated scrutiny and re-appraisal of this sort can lead finally only to assignment of safe values on which complete reliance can be placed. The committee welcomes all such information.**

Need for more Data

IN THIS CONNECTION another point implied in Dr. Sterner's discussion should be strengthened—namely, the need for more data substantiating the choice of safe exposure levels based on industrial experience. Much useful information is undoubtedly in the files of many plants. Indication of this was the fine evidence on six industrial sub-

*The incorporated safety factor in the threshold limit values, although added at times because of uncertainty in the value as related to human exposure, often actually provides an appreciable margin of safety. For this reason the correctness of the term "threshold limit" may be questioned. It might more properly be replaced with "air hygiene standard."

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stances derived from many years of plant experience that came to light last year at these meetings from the presentation of Herbert J. Weber.[1] Others should have similar material that should be brought to the attention of the Threshold Limits Committee. Like Weber's material, all of it need not be novel or presented to show need for changing existing limits; equally valuable are data confirming existing limits. As never before, interest in the value of the control of industrial environments is being shared by management generally. Greater numbers of industrial hygienists than ever before are being engaged by industry. Is it too much to hope that meetings such as these will orient the thinking of properly placed industrial hygienists to secure much needed plant information to aid in the choice of safe limits of human exposure?

The type of information needed may be listed as follows: (1) Air concentrations should be determined for the substances under study through a complete cycle of plant operations and with reasonable regularity in order to obtain a true picture of the range and fluctuations of exposure. (2) The data should have good accuracy. (3) The observations should be carried out over a reasonable period of time—a minimum of five years. (4) The air concentration data should be correlated with a good medical program. A pattern for such work is that of Dr. Sterner's 10-year study of workers exposure to butyl alcohol.[2]

There is a real need for more data based on industrial experience. The often-heard statement "the threshold limits are nothing but educated guesses" unquestionably reflects the wish at least that more data be firmly based on industrial experience to substantiate the choice of limits. As a member of the Threshold Limits Committee, I was concerned over the statement and took the trouble to review each substance in the threshold limit list for 1955 as to the basis for choice of the level. The results are shown in Table I. It is possible that everyone would not arrive at precisely the same figures, but I believe that their magnitude would not be much altered. Although the table shows that the educated guesses account for a relatively small number, it does confirm the often expressed feeling of the need for more solidly based levels. Table I shows a number of other interesting facts: (1) that most of the values have some sort of scientific basis; (2) that each level has been documented either by Warren A. Cook,[3] or by the Committee on Threshold Limits; (3) that the values based on animal experiments account for the largest number, 42%; but (4) that values having some industrial basis account for 1/3 of the total.

TABLE I.
BASIS FOR CHOICE OF THRESHOLD LIMIT VALUE*

Study Type	No. of Listings	Percent Total Listings (223)
Animal	94	42
Industry	51	23
Animal & Industry	23	10
Man	25	11
"Educated Guess"	21	9
Animal & Man	9	4
Source uncertain	3	1

*Based in part on COOK, W. A., *Ind. Med.* 14:936, 1945, and from documented material of Threshold Limits Committee A.C.G.I.H. 1953-1955.

The values ascribed to the "man" category arise from two sources—that of Nelson, et al,[4] and those more recent publications of the Dow Chemical workers, Irish, Rowe, Spencer, Adams et al.

The "Educated Guess"

A FEW WORDS should be said in defense of the "educated guess." A review of the values described as guesses indicates in the instances in which sound information has later become available that the "guess" was remarkably good. Two prominent examples only will suffice—hydrogen fluoride and uranium. A safe exposure level for hydrogen fluoride was set at 3 ppm on the very limited evidence supplied by a study in animals by Ronzani in 1909.[5] Last year a report[6] culminating many years of study of fluoride exposure in the aluminum industry, involving thousands of air and urine analysis for fluoride and studies of roentgenographic changes in bone, showed without question that air levels double the accepted limit gave rise to perceptible changes in bone in only a few individuals, and only after many years of exposure, thus validating the wisdom of this "educated guess."

In the case of uranium, an engineering bench-mark had to be "guessed" at early in the days of the Manhattan Project. After a

review of the quite limited animal data on uranium then available, Dr. Stafford Warren suggested that the "safe" exposure level for uranium be the same as that for lead, 0.15 mg/cu.m. After $500,000 and many years had been spent in research, the safe levels of exposure to uranium compounds were found to bracket this value very closely.

Levels for Cancerigens

THERE is still one group of substances for which some method should be devised for establishing safe air standards—the industrial cancerigens. How shall we establish the limits for this type of substance? Thus far the question has been sidestepped completely. As a result, with one exception, nickel carbonyl, limits taking into consideration potential cancerigenicity have not been assigned. Several industrial substances are known or suspected cancerigens; many more are suspect on the basis of animal experiments. As a suggested method of approach, the following is offered: To the level judged safe for other types of systemic injury add a safety factor for carcinogenicity. The magnitude of the safety factor is suggested to be from 100 to 500. This provides at least a second power of 10, which, from the well-known dosage-response hypothesis, provides at least a fourfold longer interval before effects may be expected to occur, or conversely at least a response with ¼ the intensity. This manner of approach has been used for nickel carbonyl. A tentatively safe level for systemic effects from repeated daily exposure has been set at 0.1 ppm; one-hundredth this level, or 0.001 ppm was set for nickel carbonyl on the basis that nickel poisoning gives rise to a substantial increase in the incidence of lung cancer. It is realized that unfortunately the safe limits for all industrial cancerigens cannot be so readily resolved. This is especially true of dye intermediates, such as benzidine and naphthyl amines whose major route of entry is not commonly via the lungs but through the skin and gastrointestinal tract. These are laundry and protective equipment problems not solvable by air control.

There are undoubtedly substances to which the suggested procedure may not strictly apply, but imperfect as it may be, the suggested method is felt to be a step in the right direction and serves better to curb exposures to industrial carcinogens than considering the problem too difficult to cope with at the present time.

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Engineering and Chemical Application of Standards

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THE WHY AND HOW of threshold limits for air contaminants have been discussed by the preceding speakers. The logical next and final consideration is the use or application of these limits in preventing occupational diseases, in avoiding complaints from exposed employees, in maintaining employee efficiency, and in promoting good housekeeping.

To engineers engaged in industrial hygiene, threshold limits provide the reference line or bench mark upon which all considerations and calculations for the control of air contamination are based. It is characteristic of engineers and of others in the physical sciences to want to reduce to numbers the problems with which they deal, because only then can they be attacked in a precise man-

ner. It has never been clear in my mind whether engineers enter this profession because of their love for and adeptness with numbers, or whether they acquire their desire to work with numbers as a result of pursuing the engineering discipline. Nor is it important to the subject matter of this paper to know which is the cause and which the effect. Suffice it to recognize at this time that this quality is omnipresent in engineers, and if industrial health problems arising out of environmental conditions are to be prevented or controlled, the physiological responses of the industrial employees will have to be translated into some physical yardstick readily understood by engineers whose function it is to regulate the environment in the best interests of the worker and of production.

Threshold limits serve several very useful purposes in the industrial health picture. Through careful studies of the air at existing operations or in existing plants, they permit deciding whether a health hazard is present or not, and if present, how severe it is. They are quite useful to the discerning physician in determining whether the health impairment of an exposed worker is attributable to his employment, and in this respect may exert significant influence on the disposition of occupational disease claims.

Where a health hazard from air contamination has been found to exist, threshold limits frequently are the guidepost indicating which avenue of control to follow to achieve a satisfactory solution to the problem. Having ascertained the avenue to follow, the threshold limits provide the only scientific basis as to how far we must journey to arrive at the desired destination.

Having alluded briefly to the principal roles played by threshold limits in industrial hygiene, let us now examine each one of these more carefully and consider their application in industry.

Evaluating Potential Health Hazards

IN THIS AGE of mechanization and high speed production, there are many places in industry where some of the materials being handled, consumed, or processed escapes into the air. Whether this airborne contaminant constitutes a health hazard depends upon its concentration in the air breathed by exposed persons as related to its inherent harmfulness. The concentration of the material in question in the breathing zones of employees is capable of rather accurate measurement. If the harmfulness of the contaminant is known, also, in terms of a safe atmospheric concentration (the threshold limit), the presence or absence of a health hazard is apparent. In this way threshold limits are applied widely in industry to decide where better control of the environment is needed and where it is not needed.

Assisting in the Diagnosis of Illness

NOT INFREQUENTLY, there is a discouraging duplicity of symptoms manifested by persons suffering from different illnesses, especially in the early stages. If the symptoms exhibited by an employee are compatible with those that might be produced by the air contaminant to which he has been exposed as well as with several other stimuli of non-occupational origin, comparison of the concentration to which he actually was exposed with an accepted threshold limit for this same material is of inestimable value in arriving at the most probable cause of the illness. If the exposure exceeds the threshold limit and the symptoms are indicative of illness from such exposure, the occupational hazard may well be the cause. If, however, the atmospheric concentration of contaminant in the breathing zone of the worker has been well below the threshold limit, it suggests to the examining physician that all other possible causes must be explored thoroughly before a diagnosis can be made.

This application of threshold limits sometimes reaches out into the compensation courts. The employee's personal physician, having only the complainant's description of his job rather than factual data to guide him in the diagnosis, not infrequently will arrive at an erroneous conclusion. Controversial medical opinions are introduced in evidence at the hearing, and the carefully measured atmospheric concentration of the material in question as compared to the threshold limit for this material is the only bit of uncontested scientific information that the referee has available on which to decide the case. This is not to say that the controverted cases usually are decided on

this basis. Other factors, many of which are not scientific in nature, play a part in the adjudication of such compensation cases. Nevertheless, testimony of this kind has been helpful in arriving at the truth in some cases, and there is hope that an increasing amount of importance will be attached in the future by compensation courts to evidence of this kind, as more and more experience is accumulated to support the threshold limits and as knowledge of this useful tool becomes more common in compensation circles.

Control of the Hazard

IT IS in the control of atmospheric contaminants that threshold limits find their most important application in industry. The judicious use of threshold limits in selecting and designing control measures and equipment will result in satisfactory working conditions at a minimum in cost and interference with production. Possibly the best way to add clarity and reality to this general observation is to implement it with conspicuous examples.

Given: a production type degreasing operation in which the parts are cleaned mechanically by immersion in a tank of carbon tetrachloride. The tank is provided with a local exhaust system, but is so wide that considerable of the grossly contaminated air at the remote side is spilling into the workroom air and nearby employees are exposed to vapor concentrations in the order of 250 ppm. Problem: how best to correct this condition.

Obviously the condition can be corrected by rebuilding the exhaust system and increasing its capacity, or by changing to a less toxic solvent. Imagine how insecure you would feel in facing this problem if there were no threshold limits to guide you. You would not have any idea how much reduction in vapor concentration is necessary to eliminate the health hazard. Even if a less toxic solvent were substituted, there would be no way of knowing whether it alone will solve the problem or whether improved process ventilation is needed, and if an increased exhaust rate is needed, how much increase is required. To be on the safe side you probably would change to a safer solvent and redesign the exhaust system with 100% capture as your goal.

How much simpler it is with threshold limits to provide a scientific basis for consideration. Obviously the exhaust system could be redesigned to capture all the vapor rising from the tank surface and from the withdrawn parts. This would have the serious disadvantage of increasing markedly the consumption rate of the solvent, carbon tetrachloride. Since methyl chloroform has physical characteristics very similar to carbon tetrachloride, if it were used instead of carbon tetrachloride the atmospheric concentration of vapor would be about the same, and since the threshold limit for methyl chloroform is 500 ppm, the problem would be solved. However, this solution carries with it a substantial cost disadvantage, methyl chloroform being more expensive than carbon tetrachloride. Therefore, let's consider using trichloroethylene or perchloroethylene in place of carbon tetrachloride. It too costs more than carbon tetrachloride, but because of its lower volatility the consumption rate will decrease if much of the loss takes place via the air entering the exhaust system. But what about solving the health hazard. The threshold limit for trichloroethylene and for perchloroethylene is 200 ppm and the vapor concentration was found to be in the order of 250 ppm when carbon tetrachloride was used. Because of the lower vapor pressure of the proposed substitutes, the amount of vapor getting into the room air will be much less and the exposure of the workers will be reduced to a value well below 200 ppm. Thus by employing the yardstick of threshold limits, two easy and certain solutions are found to this problem without difficulty.

It may be well to emphasize at this point that other important considerations must not be overlooked. All factors must be borne in mind whenever one is faced with an air contaminant control problem. Sometimes careful selection of a substitute will not not only bring the health hazard under control but also will increase the operating rate, or decrease the consumption rate of a process ingredient thereby achieving considerable cost advantage as a by-product of the change. By way of illustration, the slower evaporation rate of perchloroethylene as compared with carbon tetrachloride not only minimized the potential health hazard at a specific gravity test-

ing operation but also resulted in an annual saving of about $3000 in the cost of the liquid consumed. This, in spite of the fact that perchloroethylene is much more expensive per unit of measure than is carbon tetrachloride.

Criteria in Substitution

THE APPLICATION of threshold limits in the control of health hazards by substitution is such a useful tool that several other examples will be cited.

Solvent degreasers and cleaners are used so widely, and frequently so erratically, that it is difficult to be certain that adequate control precautions are being observed at all times, especially if the solvent in question is relatively toxic. For this reason industry is engaged in a search for effective solvent cleaners which inherently are much less toxic than those in common use today. Because carbon tetrachloride has qualities which make it an exceptionally satisfactory solvent from the functional viewpoint, it is in constant demand by all operating people who are not fully aware of its danger. However, reputable jobbers and vendors of proprietary solvents of all kinds have become increasingly conscious of the health considerations attending the use of their products and have been selecting their product ingredients on the basis of toxicity expressed in terms of threshold limits. It is heartening to note how commonly the suppliers of solvent degreasers and cleaners are using the valuable yardstick of threshold limits to concoct ever safer products to satisfy the complex degreasing and cleaning demands of industry.

It appears to us that we are on the doorstep of a new era which will see great advances in solvent cleaning safety, thanks to threshold limits. It would be remiss at this time not to mention that methyl chloroform promises to be the carbon tetrachloride of tomorrow. If properly inhibited to prevent its corrosive action on certain metals, it appears to be the perfect answer for those cleaning and degreasing jobs on which only carbon tetrachloride has been acceptable in the past.

Threshold limits have played and continue to play a key role in the control of the hazard associated with abrasive blasting of all kinds. Originally, sand was used for all abrasive blasting. This created a serious health hazard on the part of the operators and nearby employees, and not infrequently it posed a serious wear problem on nearby machinery which had not been protected during the blasting. The problem was soon brought under control for most production-type blasting by housing such operations in well ventilated rooms, chambers or booths. In addition, steel grit was substituted for sand on most work of this kind if the grit was recoverable and reusable. Because of the high cost of steel grit as compared with sand, it was not readily accepted for work in which most or all of the grit was lost. More recently, however, several types of grit have been placed on the market which are by-products of the metal smelting and refining industry. While not as economical as sand, they are much less expensive than steel grit. These substitute blasting grits came into use because the probable health hazard attending their use is much less than is the case with sand, in terms of the threshold limits of the ingredients and the amounts present. Selection of the particular by-product grit to be used on any blast cleaning job is made on the basis of availability and the probable health hazard as expressed by the threshold limits of the ingredients and the amounts present.

But the application of threshold limits on abrasive blast cleaning jobs does not end here. Since most blast cleaning jobs are not done mechanically in well ventilated booths and require respiratory protection for the operator, threshold limits enter the consideration as to the proper respirator to be worn. Supplied-air respirators or helmets require a supply of air of respirable quality under pressure. Consequently for isolated jobs where a separate blower or semi-compressor would be required to furnish air to the respirator, conventional dust respirators of the mechanical filter type may provide adequate respiratory protection depending upon the harmfulness of the dust produced as determined by the threshold limits of the grit ingredient and those of the surface being cleaned. In reverse order, of course, sand may be used with safety if the blaster can conveniently wear a supplied-air helmet and a source of respirable air for the respirator is readily available.

It must not be inferred from the fore-

going that threshold limits *per se* of a process material or the ingredients thereof determine the extent of a health hazard. The atmospheric concentration of the contaminant in the air to which the employee is exposed is equally important. But when considering a type, or class, of operations in which the employee's exposure does not vary tremendously, as a rule, from one operation to another, substantial changes in the threshold limits of the process material ingredients overshadow the smaller variations that take place in atmospheric concentration of the contaminant. This is not to say that all abrasive blasting operations produce the same concentration of dust in the ambient air, but rather that, all other things being equal, a change in the nature of the blasting material will not affect the dust concentration nearby as profoundly as it will the applicable threshold limit, if the substitute material is well chosen. For example, it is extremely unlikely that steel grit or even a substitute grit produced as a by-product in the glass or in the smelting industry and containing less than 5% free silica would create as severe a hazard as does sand in blast cleaning of unpainted surfaces. Obviously, if painted surfaces are blast-cleaned, a new factor enters the picture which may well overshadow the composition of the grit. However, here again threshold limits would be consulted in conjunction with the dust concentration to determine (1) the severity of the health hazard, (2) whether there is any advantage in using a more expensive substitute grit, and (3) what is required in the way of personal protection.

Threshold limits are especially useful in designing for the control of air contaminants in all cases where the sources are of such nature, location and distribution as to permit effective control by general ventilation. In the case of solvents or other liquids being used in a room, the required ventilation rate can be calculated very easily if the consumption rate of the liquids is known. The same is true for particulate matter if the rate of dust generation is known, or if information is available as to the dust concentration and ventilation rate prevailing at a comparable operation elsewhere. By employing the threshold limit for the dust in question, the ventilation for the operation under consideration can be calculated readily, rather than guessing what it should be or following some rule of thumb. In all existing shops or rooms where air contaminants are present in objectionable concentration, the threshold limit of the contaminants in conjunction with the current general ventilation rate (which can be measured) permits calculating accurately what is needed in the way of fans to eliminate the objectionable or potentially harmful conditions. Threshold limits remove much of the conjecture otherwise involved in problems of general ventilation for purposes of dust, fume and gas control.

Classification of Material for Control Purposes

EVEN THOUGH it is desirable to consider each problem separately, not infrequently it is expeditious to set down rules governing the control of hazards created by many operations that differ considerably in type. In such instances the toxicity of the process materials and the by-products in terms of their threshold limits may be grouped and used in conjunction with similar groupings of the other variable factors influencing the hazard, to arrive at a set of relatively few rules to cover the whole gamut of operations in question. For example, let us consider open-surface tank operations of all kinds, whether they be pickling, degreasing, alkali-cleaning, painting, plating or other treatment. By dividing all the materials involved in these operations into three groups according to their threshold limits and into similar groups on the basis of the other governing factors, it was possible to classify all possible types of open-surface tank operations into four classes as regards the ventilation rate required at the tank for adequate control of the contaminants released.[1,2] Without threshold limits to serve as a guide it would have been well nigh impossible to develop these few rules governing so many different materials and operations.

Similar codification is under consideration by American Standards Association Committee Z-9—Exhaust Systems—for other groups of processes and operations having like industrial hygiene aspects, as, for example, bulk materials handling, surface coating operations, mechanical cutting and abrading operations, and abrasive blasting operations. Without threshold limits,

such codification would be beset with unending research, consultation and guesswork of such magnitude as to make consummation dubious and as to place the final result under serious suspicion.

Experience

THERE is much merit in the proverb "the taste of the pudding is in the eating." Therefore, past experience may well be examined in the use of industrial hygiene standards to prevent occupational illnesses. In this respect, the literature is most disappointing, not because the experience has been unfavorable but rather because the literature contains few reports of first hand investigations into this relationship. The one which probably best demonstrates the use of threshold limits and the results achieved may be found in the report by McConnell, *et al.*, on the occupational disease experience in the government-owned ordnance plants during World War II.[3] Since it was my privilege to take part in this program from its inception, I can speak of it with some feeling.

When the United States first began ammunition production at an increased rate about 1940, very little information was available on the toxicity of TNT of such nature that would permit setting a threshold limit. TNT consumption in the U. S. in the period between 1918 and 1940 was essentially nil and threshold limits were not nearly so common as they are now. That TNT is toxic was not questioned, for according to the best information available about 17,000 persons in ammunition plants were poisoned, 475 of them fatally, during World War I. It was this sad experience coupled with the related problems of absenteeism, inefficiency and manpower shortage that led the War Department to undertake jointly with the U.S. Public Health Service an aggressive industrial health program in all ammunition plants. Inasmuch as the most serious potential problem was TNT, it was decided at the outset to conjure up a maximum allowable concentration for this substance, the standard to be based on the little information available as to its toxicity, comparative physiology, and the concentration that was known to be achievable by good engineering practice. This "educated guess" turned out to be 1.5 mg/m^3, a value still in common use. Reference to the report by McConnell, *et al.*, shows how closely the incidence of illness from TNT paralleled the exposure curve. Owing to the tremendous scarcity of the equipment needed for engineering control of the fumes and dust, such as motors, fans, and sheet metal for piping and hoods, the weighted-average level of 1.5 mg/m^3 was not reached until the latter part of 1944. However, the fatalities from TNT were held to 22 for the entire period of the war[4] and the total number of lost time cases was only 56 as of May 1, 1945, the end of the report period covered in reference 3. The incidence of early symptoms of TNT poisoning was quite high, and there is little doubt that the number of lost-time cases as well as fatalities would have been much higher if it had not been for the excellent periodic medical examination program then in effect in the ammunition plants, especially in the loading plants where the exposures were the worst. It is interesting to note that the case rate of early systemic effects was close to 500 per 1000 man years of exposure for the first six months of 1943 when the weighted average exposure to TNT was about 2.7 mg/m^3, and about 1/5 of this rate for the last six months of 1944 when the exposure had been reduced to about 1.4 mg/m^3.

The control program in the ordnance plants during World War II would have been inestimably more difficult, and there is little doubt in my mind that the final report would portray a different story, a much sadder one, from that told by McConnell, *et al.*, if there had been no standard for TNT. In the face of the dire shortages of equipment needed directly by the Armed Forces, and other equipment needed to produce the weapons of war, authorization to divert some of this material for dust control purposes would have been out of the question in the absence of a threshold limit to indicate how badly and where such equipment was needed. As in many other factors affecting our daily life, standards are the very foundation of industrial hygiene. Without them the engineer in this field is placed in the same position as the boy who is sent to the hardware store by his father to buy a "big" bolt. The boy would have as good a chance of getting a bolt of the right size as an engineer would have of preventing the vast majority of occupational illnesses and

complaints if there were no threshold limits.

In conclusion a few remarks are in order dealing with the philosophy of and justification for threshold limits, and are added here because they serve as a reply to the criticisms often leveled at industrial hygiene standards.

It is not unusual to hear that these limits are useless, if not even dangerous, because in the event that the atmospheric concentration is measured inaccurately, reliance on the standards creates a false sense of security on the one hand, or needless alarm on the other, depending upon whether the measured result is in error downward or upward. It requires little mental gymnastics to realize that this is equivalent to concluding that there is no sense in asking your grocer for a dozen oranges simply because he may make a mistake in counting them. By definition, threshold limits are those concentrations of contaminants which in the light of current knowledge will not cause harm to persons exposed continuously day in and day out during the normal working hours. Reference is to the concentration actually existing, not to some value that the investigator might conclude exists. Concentrations can be measured accurately, but to do so requires skill, understanding, patience and energy. It is rather discouraging to note how frequently conclusions are based on wholly inadequate data. It is not surprising either that the concentrations frequently "measured" have little relation to the true weighted average concentration.

The philosophy of threshold limits is that each one represents a concentration of the substance in question that will have no demonstrable adverse effect on the health of exposed persons. Not all persons react the same to stimuli of this nature, but rather any given population follows approximately an average random distribution pattern as regards response to atmospheric contaminants. That is to say, there is an occasional person at one end of the curve who is unaffected by relatively overwhelming concentrations and there is an occasional person at the other end who is affected by extremely low concentrations. To prevent any adverse effect upon every last man may require such low concentrations as to be impracticable. The threshold limit is merely a concentration that intersects the random distribution curve at a very low point. How low this point is for any substance cannot be stated. That it is not the same for all materials is obvious, and that it serves to prevent harm to all but a relatively few is obvious, also. Serious or irreparable damage to the occasional person who falls to the left of the threshold limit on the random distribution curve can be avoided by an appropriate medical examination program.

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Prepared Discussion

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IN AN ENDEAVOR to safeguard the health of the worker and the public from exposure to harmful substances, two basically different types of standards have evolved. One type—the threshold limit, or maximum allowable concentration—is the performance-type of standard. The other, about which little has been said by the previous speakers, is the engineering type of standard.

To make the distinction between the two types of standards more concrete, take the specific example of a stave-type tumbling mill (Fig. 1) in a ferrous foundry. Into it are placed castings with sand both clinging to their outer surfaces and in their internal cavities in the form of cores. The express purpose of placing these castings into the mill is to clean them of this sand. The mill is, therefore, by its very nature, a device designed and operated to cause sand to leave the castings and enter the ambient air. While it is true that most of this sand will

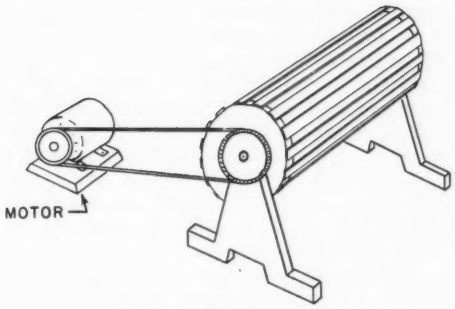


Fig. 1.
Stave mill.

fall to the floor under the mill, it is equally true that a tremendous number of free silica particles will become air-borne by the process. From the viewpoint of the performance standard, it is necessary to keep the atmosphere of the cleaning room below the threshold limit for free silica by whatever means the owner of the foundry may choose to employ.

Engineering Standards

FROM THE VIEWPOINT of engineering standards, the reasoning is somewhat as follows:

A. It is widely recognized in the foundry industry that stave mills are bad dust producers and require enclosure.

B. The industry, by trial and error, has developed a satisfactory type of ventilated enclosure (Fig. 2) which not only keeps the dust out of the workroom, but also keeps the floor below the mill free of much of the sand that would otherwise accumulate there and have to be carted away.

C. This type of enclosure, having been adopted by most of the industry, should therefore become the standard of the entire industry.

D. An engineering standard should therefore be written so specifying this enclosure with respect to structure and ventilation that any foundryman building an enclosure meeting these specifications will achieve dust control of his stave mill (Fig. 3).

Applicability of Standards

LET US EXPLORE some of the arguments for and against each of these approaches. Both aim at the same objective—the safeguarding of the worker. The principal ar-

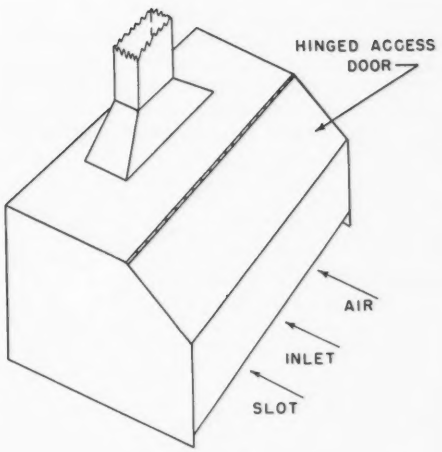


Fig. 2.
Stave mill enclosure.

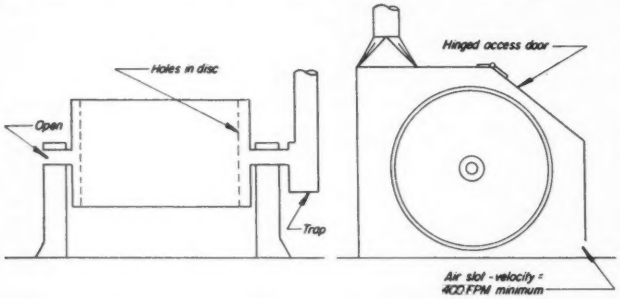
gument in favor of the performance standard is that it is noboby's business except the owner's as to how he achieves control of the hazard, just so long as he does, in fact, succeed in so doing. The corollary argument against the use of the engineering standard is that there is no positive guarantee that once the owner has invested his money in an enclosure conforming to the standard specification, the exposure of the workers in the cleaning room will be below threshold limit.

The same logic can be used to plead the case for the engineering standard. The dust load in the cleaning room air comes from many sources in addition to the stave mills (Fig. 4). If some of these sources remain uncontrolled after the stave mill has been enclosed and ventilated according to standard specification, it is entirely possible, even probable, that dust concentration in the room will remain above threshold despite entirely satisfactory dust control by the stave mill enclosure. Engineering standards thus have the inherent capacity to allow a step by step orderly approach toward the ultimate goal of achieving below-threshold concentrations in all parts of the plant at all times.

New Construction

ASSUME that a new foundry is being designed. To apply performance standards,

the foundry must first be built, placed in operation, and then subjected to air sampling and analysis. No reputable and well-informed engineer would design this new plant without seeking the engineering standards for the control of dust from the cleaning room equipment and applying them to the best of his ability. In this situation, argument arises, not as to the need for such engineering standards, but rather as to their accuracy. Should the opening for air be 3½" or should it be 4"? If the standard says 900 cfm, and the designer is firmly convinced that 450 cfm are sufficient, he should be prepared to back up his independence of judgment by later proof that concentrations are below threshold in the completed workroom when the lower value of cfm is employed.



SECTION THRU HOLLOW TRUNNION TUMBLER

Duct velocity = 5000 FPM.
Entry loss = 2.0 to 4.0 VP (depends on design)

STAVE MILL (END SECTION)

Duct velocity = 3500 FPM minimum.
Entry loss varies with take-off 0.25-0.50 VP.

EXHAUST VOLUMES

Square mill side diam. in	Round mill I.D. in inches	CFM	
		Trunnion	Stave*
	Up to 24 included	430	800
Up to 24 incl.	24 - 30	680	900
25 to 30 "	30 - 36	980	980
31 to 36 "	36 - 42	1330	1330
37 to 42 "	42 - 48	1750	1750
43 to 48 "	48 - 54	2200	2200
49 to 54 "	54 - 60	2730	2730
55 to 60 "	60 - 66	3300	3300
61 to 66 "	66 - 72	3920	3920
67 to 72 "		4600	4600

*For lengths over 70", increase CFM proportionately.

Fig. 3.
Tumbling mills.

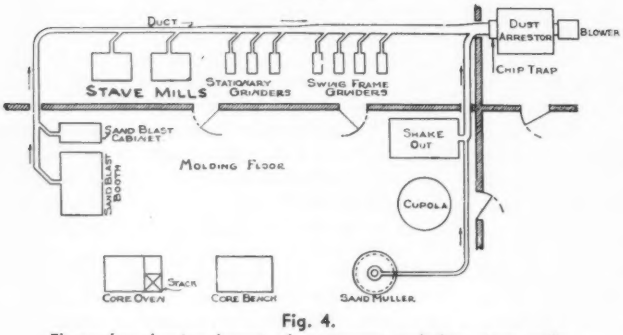


Fig. 4.
Floor plan showing layout of equipment including stave mills.

Hinged access door

Air slot - velocity = 4000 FPM minimum

Double Jeopardy

WHERE the engineering standard is a tool in the hands of an enforcement agency, the user of such standards frequently fears that he is placed in double jeopardy. He has to comply with engineering standards with which he may disagree, and then, having employed all such standards in every operation, may still be not in compliance with the performance standards. The wise enforcement agency will let it be known that it will not permit such double jeopardy to occur, and that any factory owner who adheres throughout to

the best engineering standards known to the agency will not be asked to re-do the job.

What, then, is the plight of the workingman caught in the middle? Is he likely to become a pawn, forced to work in an unhealthful atmosphere because the sponsoring agency is unwilling to admit a mistake as to the effectiveness of its engineering standards? We are indeed fortunate that the quality of our engineering standards is so high that such cases occur infrequently. Where they do occur, they are almost always borderline cases with respect to the threshold limit and are well within the factor of safety built into the threshold limit itself.

Emission Standards

THE RELATIONSHIP between performance and engineering standards for in-plant atmospheres has its counterpart in that between atmospheric and emission standards in the field of air pollution. A major difference is that, whereas there are a large number of accepted threshold limits for in-plant atmosphere, there are almost no standards commonly accepted for the outside atmosphere.

The emission standard is very much in the same position as the engineering standard for in-plant controls in that adherence to it by one specific stack does not guarantee the cleanliness of the air of the surrounding community. Thousands of factories have put in-plant engineering standards to the test and proven that when every source of contaminant release is controlled as specified by the applicable engineering standard, the result has been to maintain the factory atmospheric contaminant concentration below the threshold limit. Such beautiful demonstrations, which are easy when the atmosphere in question is confined by four walls and a roof, become almost impossible to find in the open air over cities and towns. However, it is reasonable to believe that what works in a small confined space will also eventually work in the largest of confined spaces, that having the inevitable inversion ceiling as a roof and four topographical or meteorological side walls.

Standard for the Open Air

LET US LOOK once again at the principal argument for performance standard in the in-plant situation, *i.e.*, that it is nobody's business but the plant owner's as to how he achieves control of the hazard—so long as he does so. Is this doctrine equally applicable to the air over a city? It hardly seems so. No individual owner or group of owners could or would be willing to take the responsibility for the maintenance of a specified level of contamination of the air of the community in which they operate. They would quickly recognize the many factors over which they do not have the same measure of control that exists inside the factory building. For them, the emission standard is a boon.

Here the argument is not with the concept of the emission standard, but with its numerical value for a particular installation. One of the most interesting developments of the past decade along these lines has been the fact that public utility power plant designers have consistently specified equipment for fly ash control to meet emission standards much more stringent than public regulatory bodies have required. Industrial foresight and conscience is in this, and a number of other industrial hygiene and air pollution control fronts, well ahead of public regulatory demands.

Conclusion

IN BOTH these areas, this is the hope of the future. The dictum of a Massachusetts court of many years ago that the best plants in an industry may reasonably be used to set the standard for the entire industry provides the real key to future progress. America is blessed with real industrial leadership and statesmanship. Neither industry's leaders and statesmen nor the public will tolerate the acceptance of standards which are below the best that industry can, by example, provide.

Summary

THERE are two general types of standards —performance type standards and engineering standards. The former specify threshold limits. The latter specify the performance of a particular piece of equipment. Arguments are given pro and con as to the relative merits of these two approaches to the same objective—the safeguarding of the worker. The engineering standard approach is particularly valuable in new construction where no equipment

exists at which to measure atmospheric concentration before designing safeguards. The similarity of engineering standards for the in-plant situation to emission standards for atmospheric pollution control is noted.

Prepared Discussion

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THIS COMMENT and discussion of the excellent paper presented by Dr. Brandt will be directed to the legal aspects of the application of threshold limits in the form of maximum allowable concentrations for the control of air contamination.

May I identify myself as one who has served as counsel for industrial organizations; and while my views may be prejudiced on their behalf, I feel that the industrial point of view is important in our discussion of this matter.

It is needless to say that today industry is prepared and wishes to accept full responsibility for the control of potential hazards incident to employment. Simply stated, it is good business both from the financial standpoint and also in the promotion of industrial relationships for employers to concern themselves with the protection of employees from all types of industrial injuries, be they accidental or resulting from occupational disease. The ultimate cost of compensation for such injuries may well exceed the cost resulting from installation of effective methods for engineering and medical control, aside from the fact that the employer's relation to his employees is promoted when employees know that the employer is doing everything practical to effect protection.

Question arises to the propriety and advisability of the adoption of codes of industrial hygiene defining maximum allowable concentrations of toxic materials. The word "code" is defined as follows: "A body of law established by the legislative authority of the state, and designed to regulate completely, so far as a statute may, the subject to which it relates." The adoption of codes having the full force and effect of law is unnecessary, inadvisable, and may well lead to unfortunate problems of administration to which brief reference may be made.

Under the constitutions of the various states and the powers granted to state Departments of Health and state Departments of Labor, there exists adequate authority for such departments to effectively control any hazardous condition injurious to health. As a practical matter, there is no legal need for the adoption of codes prescribing maximum allowable concentrations. It is fair to state that state Departments of Health and state Departments of Labor administering divisions of industrial hygiene have enjoyed the confidence of the public, including both management and labor, and our several state departments have been and are doing excellent jobs in the administration of their affairs. Therefore, the use of maximum allowable concentrations should be in the nature of serving as a guide to industry with particular reference to engineering standards. Industry has and will continue to seek the advice of proper state departments to control hazardous conditions effectively, and the desired objectives will be obtained through education and dissemination of information through the cooperation between state divisions of industrial hygiene and industry rather than the attempted enforcement of a given code as a matter of law.

Dr. Brandt and Mr. Stern have discussed in detail the practical uses of threshold limits with the purpose of eliminating or controlling occupational hazards. With all of the information presently available to science, it is seriously to be questioned whether the present schedule of recommended maximum allowances of concentrations are scientifically correct. True, they represent the best thinking of those scientists who have studied the problem; however, it is a fact that from day to day, industrial processes are changing, new chemical compounds are coming into commercial use, and tomorrow some new problem may be presented to industry and to public administrative agencies entirely different from any that may have been presented before. Industry welcomes technical information with respect to the existence of occupational hazards. They will continue to welcome technical advice as to practical methods of control. It must be remembered that in-

dustry seeks the maximum production of its materials at minimum cost; and if our competitive system is to be retained and business is to succeed, bureaus of industrial hygiene must assist in the attainment of this goal by the simplest and most inexpensive methods possible.

No one would contend that it is the duty of the hygienist to tell the manufacturer how to run his business. Many industrial processes are so secretive and complicated and developed over an extended period of years that it is frequently impossible for an industry within a limited period of time to rearrange that production process to give effect to all of the methods of control that the hygienist would recommend. What is needed is cooperation between state departments and manufacturers, not additional laws on our statute books that may be used to the prejudice of state departments as well as manufacturers.

There is one other thought which is worthy of consideration. Assuming that threshold limits of maximum allowable concentrations are established by law, the administration of such codes may prove to be embarrassing to state departments charged with their administration and to industry at the instance of organized pressure groups of representatives of the public, labor unions, or possible competitors. Assuming the adoption of codes, it is a fact that occasional violations may occur resulting from breakdown in machinery or equipment. Immediately the manufacturer is placed in the position of having violated the law although such violation may be absolutely unintentional and may be readily corrected. State Departments of Health and Labor do not need to be told by any organized group as to what they can or should do in the administration of their functions. Therefore, a better result will be obtained if use is made of the information developed by our scientists as to permissible concentrations not because some law requires this be done, but because it is simply good business to comply.

Encyclopedia of Instrumentation for Industrial Hygiene

INDUSTRIAL HYGIENISTS and workers in allied fields will be interested to know that the heralded encyclopedia on industrial hygiene instrumentation is now generally available. The book is divided into seven sections, each of which includes a comprehensive review of instrumentation in the area being considered, technical papers on special problems or types of instruments used, and descriptions of available instruments, mostly commercially available. The sections include the seven areas of instruments: for measuring air contaminants in occupied spaces; for use in laboratories; for air pollution and meteorology; for air velocity and metering; for sound and vibration; for ionizing radiations; and for ultra violet, visible and infrared energy.

This Encyclopedia brings together in one place a fund of specific information on instruments within the scope of the book. It was produced through the combined efforts of personnel of the University of Michigan, manufacturers' research directors and designers, authorities in the several areas of instrumentation, and a staff of experts assigned by the U. S. Public Health Service to assemble and edit the contents of the book. The comprehensive reviews include progress in the individual field of instrumentation, problems presented, limitations of present instrumentation, and needs not met by instruments now available. The descriptions of available instruments include the name of the instrument; name of the manufacturer; intended and special uses and adaptations; operating principle; physical description; performance data, such as sampling rate, range, sensitivity; inteferences, limitations and safety hazards; price; operating instructions; calibration instructions; maintenance instructions; photographs, line drawings or wiring diagrams; bibliography.

The material in the book comprises some 1243 pages, 9 x 12 inches, with 1400 illustrations, charts and diagrams. Copies may be obtained through the University of Michigan Publication Distribution Service, Ann Arbor, Michigan. The book is priced at $30.00.

Automatic Instrumentation for Air Pollution Monitoring

A Progress Report on Automatic Directional Air Sampling

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FROM THE research laboratories and instrument manufacturers throughout the country have come many instruments and devices useful in evaluation of contaminants in the outdoor atmosphere. The designs of most of the currently available instruments follow established scientific patterns and obey the fundamental laws of chemistry or physics. Within their limitations these instruments are able to assist in shedding some light on what is present in the outdoor atmosphere.

In practical application, however, an investigator is confronted with one very significant limitation which must be understood clearly when interpreting field data. The contaminants collected or measured represent only those which are directed into the air sampling intake port or tube leading from the outdoor air to the inner workings of the sampling or testing device. Unless full consideration is given to this fundamental factor, studies of outdoor air contamination can result in very misleading deductions. It remains with the individual investigator to employ his instrumentation in such manner as to provide reasonable assurance that useful, objective data will be obtained.

The many variables, both controllable and uncontrollable, which reflect upon the validity of samples of air contaminants are discussed in a voluminous literature on this subject. Generally, it is the objective of the person conducting a field study to arrive at some conclusion based on a preconceived notion of the presence of specific air contaminants. In some instances, the investigator may have embarked upon a broad background type study to evaluate the nature and quantity of air contaminants present in the atmosphere.

One of the more perplexing problems faced by official agencies, in New Jersey and elsewhere, is that of establishing beyond reasonable doubt that the ground level concentration of an air contaminant is emanating from a specific point or industrial source. The determination of the maximum concentration of air-borne chemicals or other air contaminants at ground level has also proved to be a difficult problem.

Continuous automatic recorders are now commercially available for a relatively small group of common atmospheric contaminants. Experimental continuous recorders are being tested in various research projects for evaluation of still other forms of air contaminants. Data collected by such continuous recording methods, when correlated with meteorological information, can be very useful in determining maximum ground level concentrations and pin-pointing sources of certain air pollutants. These instruments, moreover, are being designed for the measurement of but a very small percentage of the common air contaminants and few have the specificity required for utilization in official agency actions.

The present state of our knowledge of air contamination evaluation forces us to rely upon test methods which are based upon the analysis of airborne substances collected by means of filtration, absorption, adsorption, impingement, precipitation, condensation or combinations of these methods. Such methods generally require long sampling peri-

Presented at the Seventeenth Annual Meeting, AMERICAN INDUSTRIAL HYGIENE ASSOCIATION, Philadelphia, April 26, 1956.

Fig. 1.
Eight point, silver rotary switch installed in commercially available wind vane.

ods; in some instances ranging from 24 hours to one week. During these long sampling periods, meteorological conditions including wind direction, speed and relative humidity will have varied or completely changed in characteristic. Therefore, concentration of contaminants, as indicated by subsequent analysis, represents an *average concentration* at the test site for the sampling period. It is generally impossible to relate the contaminant collected at the test site with a point source. The same applies to the estimation of the maximum ground level concentration down wind from a source.

Our experiences and the reported experiences of other investigators have indicated that the procedure of chasing a smoke plume with mobile sampling equipment is a difficult, if not an impossible, method for reliable ground level sampling.

We in the air sanitation phase of public health in New Jersey have the responsibility of responding to atmospheric contamination complaints made by residents of our state and assisting local governments in the legal control of air pollution allegedly causing health hazards, property damage, discomfort, crop damage, and nuisances. Studies in these categories usually imply liability on the part of the source and such projects must be planned carefully and carried out in such manner that there can be no question of the validity of the findings and conclusions.

When field studies are initiated to evaluate the extent of pollution in the area of complaint and to establish source, many days or weeks may be spent by around-the-clock shifts of field personnel, only to pro-

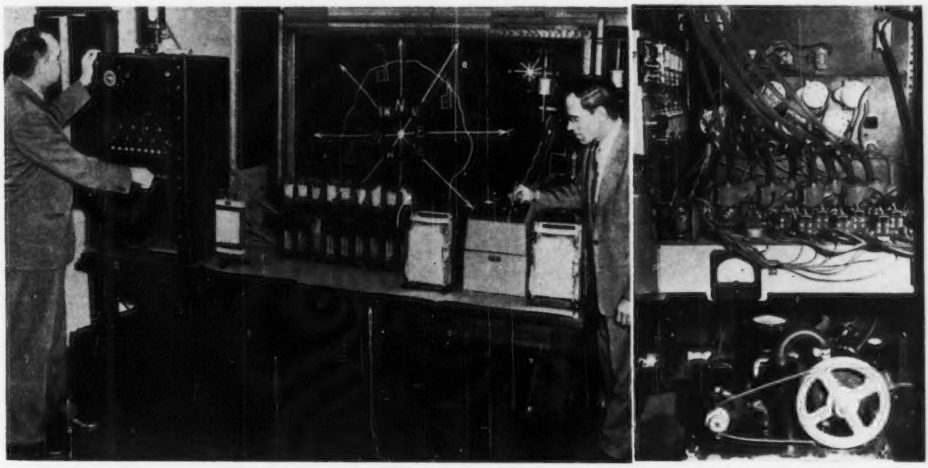

Fig. 2 (left): Component parts which make up sampler. Left to right, control unit, rotometer, impinger rack, wind speed and direction recorders, anemometer and vane. Fig. 3 (right): Interior of control unit showing relays, solenoid values, timers, manual values for calibration of air flow, air pump and other circuits for control of sampling conditions.

Fig. 4.
Complete directional sampler unit as set up for operation with 55 foot retractable tower.

duce data which would indicate that no logical basis for complaint exists or the source cannot be accurately established. Residents of the area usually reply with the statement, "You should have been here last week"; "You should test when the air is heavy," or "You didn't test when the wind is right." It is very probable that they are correct in these statements. Unfortunately, economics prevent the pursuit of long continuous studies at one location and the result is usually a further irritation to an already aroused and confused group of citizens. Local legal action is impractical without accurate supporting technical evidence.

Scores of such experiences, combined with our desire and need for a practical method for collecting ground level concentrations of contaminants under controlled conditions, have led us to the development and experimental application of an air sampling device designed to compensate automatically for some of the more significant variables.

Our instrument is basically an automatic directional air sampler. It is designed to be operated at one test site and to collect eight samples, each representing the contaminants carried to the test site from one of eight 45° sectors of the compass. The circuits can be altered to control wider sectors of say, 90°, collected in four receptacles.

A wind vane (Fig. 1) tripping an eight point switch, sets in motion one sampling device corresponding to the direction of the wind. The collector device may be filter, impinger, absorber or other apparatus operated off solenoid valves piped to an air line manifold or sampling devices operated on line current from controlled electrical outlets. Each sampler control is wired in parallel with a small timer to compute total respective operating time (Figs. 2 and 3). To avoid obvious error due to wind movements or velocities below the threshold of sensitivity of the wind vane, an automatic low wind speed cut-off is provided. This circuit disconnects the directional samplers and activates a sampler which represents a non-directional sample under wind speeds below one mile per hour. This "still-wind" sampler remains in operation regardless of the direction indicated by the wind vane.

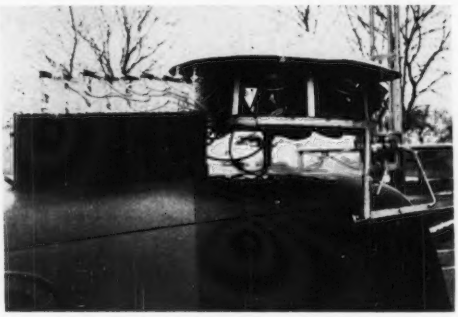

Fig. 5.
Impingers and high volume filter samples mounted on roof of vehicle and operated simultaneously under directional control.

Other features which have been included in the pilot design or are being considered for modifications in this unit are: (1) A high wind speed cut-off to stop all samplers when air movements exceed a pre-selected speed; (2) A control to limit operation of the samplers to pre-selected ranges of relative humidity; (3) A rainy weather cut-off; (4) A timing device to limit operation to a specific time of the day or night.

Such a combination of automatically controlled circuits permits a broad pre-selection of meteorological conditions under which ground level directional samples may be taken.

The entire unit is mounted in a small

truck (Figs. 4 and 5) equipped with a retractable tower for the wind vane and anemometer. Our brief experience in field operation has indicated that the time of one man for about one hour a day is required for checking the equipment once it has been set up for operation. Security for the equipment must be taken into consideration. A watchman may be necessary to ward off small boys and junior space cadets.

Fig. 6 shows a circular plot of SO_2 concentrations detected at one location over a period of approximately three days. Figs. 7 through 9 show the results of a series of three 4-day studies made at three locations around a suspected source of copper-dust which was alleged to be causing neighborhood paint discoloration. Fig. 10 is a composite of the data from the three test sites shown in Figs. 7 through 9.

Field experiences with the instrument have been limited. Each field application has revealed mechanical or electrical weakness, some of which can be corrected only by a complete redesign of circuits.

To date, no conclusive evidence can be offered to establish the value of this technique. Our experiences have, nonetheless, pointed up some of the factors which should be taken into consideration in any future development of this approach to ground level sampling. The following conclusions and recommendations are offered without deference to the availability of suitable electrical or

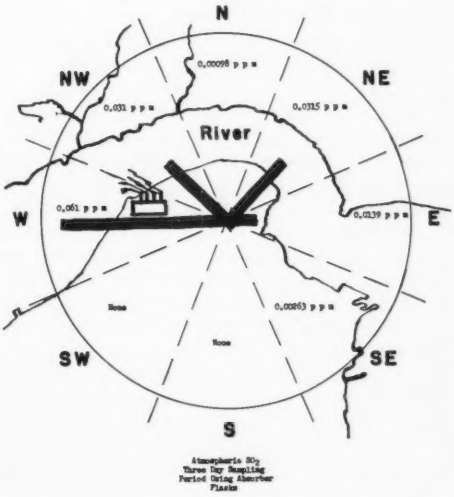

Fig. 6.
Rosette plot of concentrations of SO_2 collected at one test site. Suspected source as shown.

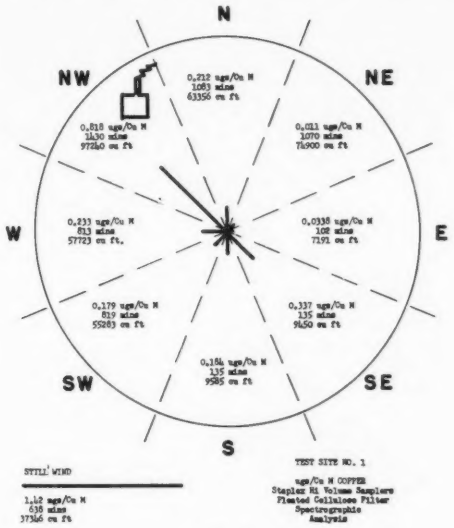

Fig. 7
Rosette plot of concentrations of copper collected at one of three test sites in the neighborhood of a suspected source.

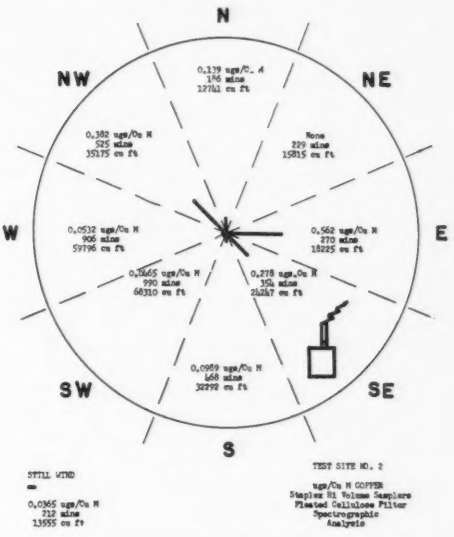

Fig. 8.
Second test site in series referred to in Fig. 7.

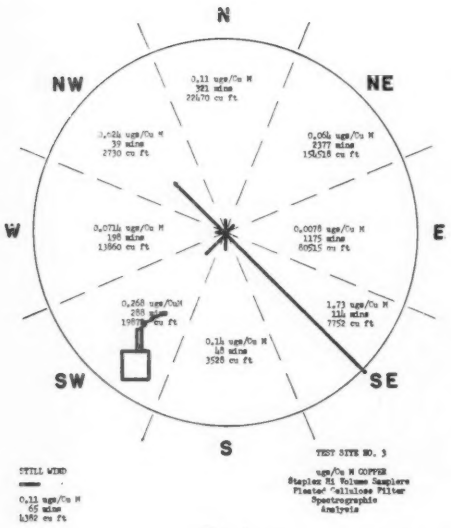

Fig. 9.
Third test site in series referred to in Fig. 7.

electronic circuits to achieve the desired end:

1. Experiments have indicated that during a very substantial portion of sampling periods, the linear air movements are below one mile per hour. During these periods, samples are not taken under directional control. If it is reasonable to assume that ground level concentrations become greater with decreased dilutions resulting from lower wind speeds, it would then appear that the instrument falls short in failing to provide directional data in the area of special interest. It appears desirable to explore the possibility of obtaining a directional control sensitivity at a much lower order of magnitude. A directional control having a sensitivity on the order of 20 feet per minute air movement or lower appears to be a desirable design criterion. An effective dampening action should be provided to eliminate rapid fluctuation between sectors.

2. Completely automatic cut-offs should be incorporated into the circuits to suspend sampling until all pre-established conditions of meteorology are favorable. Favorable that is, from the viewpoint of obtaining samples which will be reasonably representative of the specific circumstance which prompted undertaking of the field study.

3. Studies to establish the source of an air contaminant are, as a general rule, undertaken in built-up neighborhoods. Our experiences have indicated that with a mobile tower 55 feet high supporting the wind vane it is almost impossible to avoid interference of wind movements caused by buildings or trees of greater height. It is questionable if a higher mobile tower would be practical. An electronic circuit designed to permit installing the vane at a suitable unobstructed location in the general neighborhood and the sampling unit at the site of special interest might be a solution to this problem.

In summary, the directional air sampler discussed here has not yet been proved an effective tool for establishing the source of air contaminants. Experiences with the device have resulted in the definition of certain design criteria which should be met in future development of directional sampling. The need is great for pin-point monitoring procedures for official agency use. There appears to be ample justification for time and money spent on further exploration into this technique.

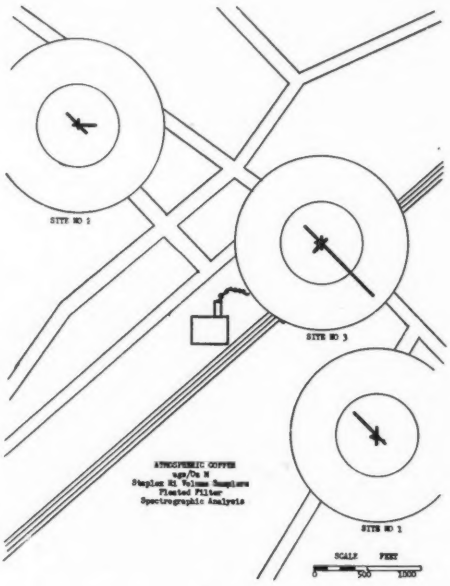

Fig. 10.
Composite plot of concentrations shown in Figs. 7 through 9 superimposed over municipal map. Suspected source is as shown.

A Versatile Portable Air Sampler

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A dependable high vacuum portable air sampler with means for positioning the sampling head is described in detail. The description would enable the average small shop to fabricate the unit without undue difficulty. The sampler has been in successful use over a period of twelve months.

A SAMPLER developed at the Los Alamos Scientific Laboratory has fulfilled a need for a dependable, high vacuum, portable air sampler with the sampling head capable of being positioned in the zone of interest. The position of the sampling head can be varied from approximately four to seven feet in height and through a 20° arc. Approximately six to eight shop hours are required to make the necessary parts and assemble the unit. The air sampler was developed from a model originally designed by O. M. Wisdahl.*

Description of Sampler

THE BASIC unit is a Gast pump, Model 0440, mounted on a cast iron base. Portability is achieved by the addition of two six-inch wheels with rubber tires. The wheels are mounted to the cast iron frame by an axle held against the frame by rods as shown in Fig. 1. Bushings must be fitted in the wheels when using ¼-inch axle. To move the sampler, it is only necessary to tilt the unit by means of the sampling tube, which serves as a handle. The unit, when at rest, is maintained in a level position by a rod of suitable length attached to the front of the base.

The air sampling train is shown in Fig. 1. The connections from the pump are ¼-inch brass pipe fittings. The ¼-inch globe valve provides a means of adjusting the air flow. For our use, the sampler is regulated to provide a 2 cfm sampling rate. The air flow measuring device is a Magnehelic gauge, reading one to four inches of water, tapped across an orifice tube. A small glass capillary tube is inserted in the tubing to the Magnehelic gauge to dampen fluctuations in the gauge.

The orifice tube is constucted of brass tubing (⅜" O.D. - .065" wall) with approximately a ¼-inch orifice. It is connected to the telescopic sampling tube by rubber tubing. The details of the telescoping sampling tube are shown in Fig. 1. The packing gland for the telescoping tube is constructed from a ½-inch brass pipe coupling and a ½- to ¼-inch brass reducing

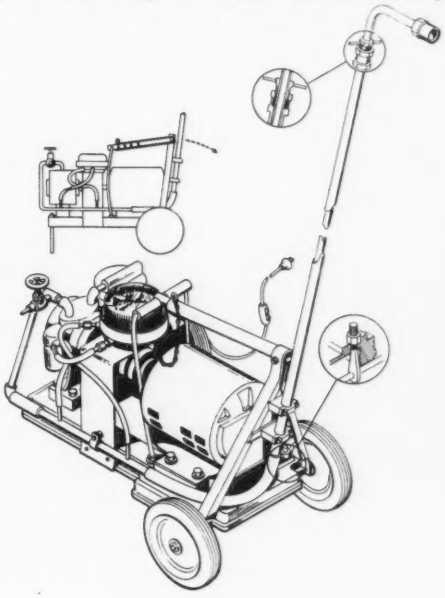

Fig. 1.
Portable Air Sampler.

This document is based on work performed at the Los Alamos Scientific Laboratory under the auspices of the Atomic Energy Commission.

*Formerly with Rocky Flats Plant, Dow Chemical Company, and now with Boeing Airplane Company.

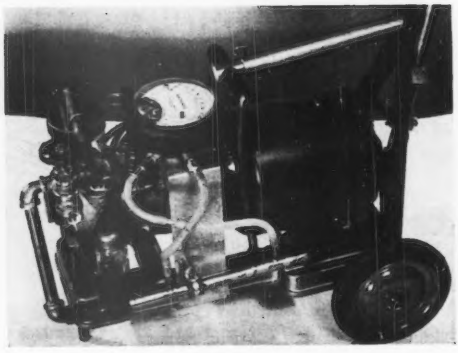

Fig. 2.

bushing. No modification is required on the coupling except that the copper tube is silver-soldered to the coupling instead of having a screw connection. Also, to enable the bushing to compress the O-rings with only hand tightening, it is necessary to loosen the screw fit between the coupling and bushing by running a ½-inch pipe tap into the coupling. The ½- to ¼-inch bushing is modified by drilling out the internal threads so the ½-inch copper tubing will slip through smoothly, and by the addition of two small rods as handles for tightening the packing gland.

The packing gland consists of two O-rings between steel washers. The end of the ½-inch tube is bent at a suitable angle and fitted with an adaptor to hold a filter paper holder or a cascade impactor. Details in Fig. 1 indicate the manner in which the sampling tube is mounted to the unit.

The sampling head is positioned by adjusting the length of the sampling tube and by adjusting the position of the aluminum tube on the aluminum rod by means of the pin. The aluminum tube and rod form a handle for lifting and carrying the sampler.

The galvanized iron, sheet metal guard over the exposed shaft of the motor and pump serves as a mounting plate for the Magnehelic gauge and electric cord holder. An over-all view of the completed sampler is given in Fig. 2.

Discussion

THE SAMPLER has been in use at the Los Alamos Scientific Laboratory for twelve months. Little difficulty has been experienced with the unit when oil levels were maintained properly. Lint from the filter paper collects on the wire strainer installed in the pump intake port. When sufficient material collects, the pump operates at a very high vacuum and excessive oil is blown through the pump. This screen should be removed or cleaned at rather frequent intervals.

The sampler can be adapted for breathing zone sampling by utilizing a rubber tubing with suitable attachments for holding a sampling head and for connecting to the sampling tube of the unit.

Position Available

SAN BERNARDINO County, California, has an opening for an Air Pollution Control Officer. The Officer is to have full responsibility for the development and management of the program of the Air Pollution Control District. Starting salary is $647.00 a month; maximum salary is $786.00. Applicants must have education and experience equivalent to a college degree with a major in engineering, and four years experience in any one, or combination, of the following: air pollution control, industrial hygiene engineering, public health engineering, or similar fields. Applications and further information may be obtained from the Department of Civil Service and Personnel, 236 Third Street, San Bernardino, California.

Determination of Internally Deposited Radioactive Isotopes from Excretion Analyses

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APPLICATION of excretion analyses to the quantitative estimation of total body burden requires that one have prior knowledge of the relationship between total body burden and excretion level as a function of time after exposure. In other words, one must know the excretion rate, preferably the excretion rate by man, of the material in question.

The excretion rate of specific radioactive nuclides by man is not always available, which necessitates the use of data collected from experimental animals. Extrapolation of animal data to man is subject to considerable criticism. There is no way to circumvent such criticism, however, until adequate experimental data have been collected from human subjects.

Urinary Excretion

URINE ANALYSES are usually used as the basis for the determination of total body burden although theoretically fecal analyses may be used once the relationship between total body burden and the fecal excretion rate is established. Fecal analyses are seldom used, however, because of the greater difficulty and inconvenience of collecting a sample representing a specific time increment and because processing the samples is usually much more difficult than for urine specimens.

For mathematical convenience, or because of lack of adequate data, it is usually customary to express urinary and/or fecal excretion as simple exponential functions of time. In this way the convenient concept of biological half-time of materials in the body may be employed. The calculations of values for maximum permissible body burdens given in Handbook 52 of the National Bureau of Standards[1] and in the Recommendations of the International Committee on Radiation Protection[2] embody the concept of the biological half-time and thereby assume simple exponential excretion with time.

This concept assumes that once the radioactive material enters the body it is retained in a single compartment or that

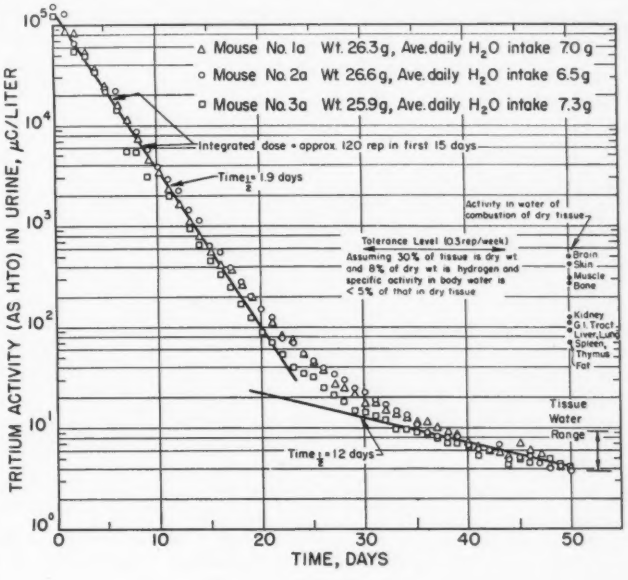

Fig. 1.
Fixation and excretion of tritium by the mouse.

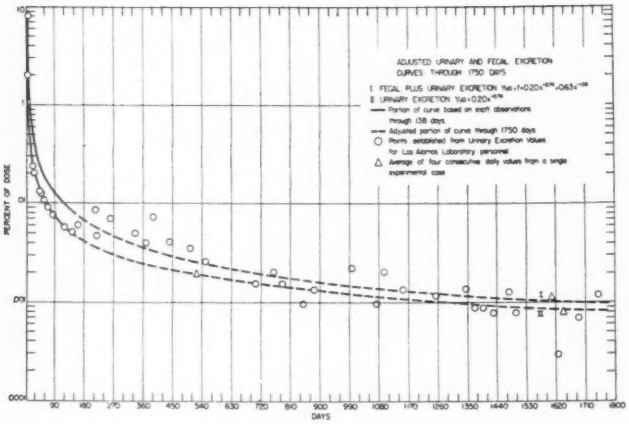

Fig. 2.
Urinary and urinary plus fecal excretion of plutonium (over 5 years) administered intravenously to man.

the rate of elimination from one of several compartments controls the overall excretion rate. In many cases experimental data indicate that these assumptions are not strictly true, over infinite time, even for materials for which the elimination process may seem on first appearance to be relatively simple.

Fig. 1 shows the urinary excretion of tritium by the mouse following a single injection of a relatively high dose of tritium in the form of HTO.[3] These data show that the tritium was excreted as a simple exponential with a half-time of 1.9 days until the activity in the urine had dropped to approximately 0.1% of the original value, beyond which the urinary excretion rate became slower, the biological half-time changing to approximately 12 days. Thompson,[4,5] has followed the excretion rate of injected tritium still further and has demonstrated the existence of tritium compartments in the body with biological turn-over times of 90 days or longer. It is reasonable to assume from the data in Fig. 1 that the 1.9-day half-time represents the rate of elimination of tritium from the body water compartment and, therefore, represents the rate of turn-over of the total body water. The longer biological half-times represent the mobilization and excretion of tritium that has exchanged with organically-bound hydrogen of the tissues. These data demonstrate clearly that the rate of excretion of tritium cannot be represented by a single exponential over infinite time. Under these conditions the determination of total body burden from a single urine analysis can be certain only provided the entire urinary excretion curve (over the period of interest) and the time between exposure and collection of the sample are known. In many instances (as in the example given above) the assumption of simple exponential excretion does not produce serious error. In the case of exposure to HTO, the size of the body water compartment is so large, compared to those compartments with slower turnover times, that the tritium in the total body water comprises the major contribution to the total radiation dose. It is not likely one would build up enough tritium activity in the organic components of the tissues to contribute significantly to the total dose before the source of contamination was discovered and corrected.

Plutonium, unlike tritium, is a material for which the rate of urinary and fecal excretion continues to change with time. Fig. 2 shows the percent of the original dose of plutonium excreted per day by human subjects as a function of days after exposure, over a period of five years.[6]

These data show that about 0.8% of the intravenously injected dose was excreted on the first day and that only during finite periods of time could the excretion curves be represented by simple exponentials. Even after five years the rate of elimination of plutonium from the body still seems to be changing. For calculating integrated radiation dose and diagnosing body burden the excretion rate of plutonium over long periods would appear to be expressed most conveniently as a power function of the type

$$Y = at^{-c} \qquad (1)$$

where Y is the excretion rate in fraction of injected dose excreted per day, t is the time after exposure in days and a and c are constants.

One might justifiably ask why such data are not expressed as a series of exponentials in preference to the power function. The choice of expression depends on the specific application of the data.* If one is interested in applying the data to a study of the fundamental processes that take place in the body, i.e., analyzing the system in terms of compartments and rates, assuming first order kinetics, then mathematical analysis leads to exponential expressions. In an analysis of this kind the power function has no simple meaning. If, however, one is interested in applying the data over long periods of time to make calculations and estimates in problems similar to those from which the original data were obtained, the power function has certain advantages. It can be integrated and differentiated easily which, in the specific case of internally deposited radioactive isotopes, facilitates the calculation of integrated radiation dose and the prediction of body burden from excretion data.

On the basis of the above general power function expression, the best curves of fit to the data shown in Fig. 2 were established and constants a and c evaluated using a method of successive least squares approximations. The specific expressions for the rates of urinary and urinary plus fecal excretion of plutonium by man over a period of 5 years are

$$Y_u = 0.002\ t^{-0.74} \quad (2)$$

$$Y_{u+f} = 0.0079\ t^{-0.94} \quad (3)$$

where Y_u and Y_{u+f} is the *fraction* of the injected dose of plutonium excreted per day in the urine and the urine plus feces, respectively, and t is the time after exposure in days.

It should be emphasized that the errors in the constants of the expressions may be of the order of 10%. Integration of Equation (3) for urinary plus fecal excretion between limits of 0.5** and x + 0.5 gives the total excretion of plutonium over time t = x. The data in Table I show the total amount of plutonium excreted during periods of time ranging from 10 days to 50 years. The calculated values agree very well with the experimental data. From the values in Table I it appears that the concept of a biological half-time cannot be applied in the case of plutonium and solution of the integrated expression for the 50% excretion time suggests that about 200 years may be required for man to eliminate one-half of his body burden.

TABLE I.
INTEGRATED VALUES FOR URINARY-FECAL EXCRETION OF PLUTONIUM IN PER CENT ADMINISTERED DOSE AT VARIOUS TIMES

Days after Injection	Years after Injection	Amount of Pu Excreted (in % Administered Dose)
10		2.5
20		3.2
22		3.3
30		3.7
60		4.5
90		5.0
120		5.4
150		5.7
180		5.9
210		6.2
240		6.3
270		6.5
300		6.7
330		6.8
360	1	7.0
720	2	8.1
1080	3	8.8
1440	4	9.3
1800	5	9.7
3600	10	11.1
5400	15	12.0
7200	20	12.6
10800	30	13.6
18000	50	14.6

The fractional retention of plutonium (R_t) at the end of any time t may be obtained by subtracting the integrated expression for fractional rate of excretion (Equation 1) from unity, in accordance with the following expression:

$$R_t = 1\text{-}a\int t^{-c}dt = 1\text{-}\frac{a}{(1\text{-}c)}\,t^{(1-c)} + C \quad (4)$$

According to the above mathematical expression, total retention becomes negative for very large values of t, which is physically impossible. This apparent discrepancy arises because the value for c in the excretion equation (Equation 3) is <1. The mathematical divergence, however, occurs far beyond the point of biological interest since the retention becomes negative only at $t > 10^{30}$ days.

For a large number of other materials body retention and urinary and fecal ex-

*The author is indebted to C. J. Maletskos and Dr. E. C. Anderson for a major part of this interpretation.

**Arbitrarily chosen as a lower limit of integration because the power function is divergent for small values of t.

cretion as functions of time fail to conform to single exponential expressions over the entire period of interest. Outstanding studies of the retention and excretion of radium by man were reported by Norris, Speckman and Gustafson.[7] They were able to measure the amount of radium administered and retained by patients in the Elgin State Hospital, Elgin, Illinois, who were given several weekly injections of radium chloride in 1931.

On the basis of assumptions drawn from animal experimental data they expressed the retention function for radium in man by a general power function of the type

$$R_t = At^{-b} \qquad (5)$$

where R_t is the fractional retention of radium t days after injection, A is a constant which is equal to the fraction of the injected dose retained when t is equal to 1, and b is a constant. When they applied the above expression to their data they obtained the following specific expression for the retention function of radium in man:

$$R_t = 0.54t^{-0.52} \qquad (6)$$

Differentiation of Equation (5) with respect to time gave the expression:

$$\frac{dR_t}{dt} = -Abt^{-(b+1)} \qquad (7)$$

in which $\frac{dR_t}{dt}$ is the rate of change in fractional retention with time. The expression is negative since the fraction retained must always decrease. As excretion is the rate of change of retention and is considered positive when retention is decreasing, the rate of fractional excretion, previously defined as Y, is equal to $-\frac{dR_t}{dt}$ and, therefore,

$$Y = Abt^{-(b+1)} \qquad (8)$$

Their substitution of the appropiate constants from Equation (6) into the differentiated form of the retention function gave

$$Y = 0.28t^{-1.52} \qquad (9)$$

as the expression for the fraction of the injected dose (Y) of radium excreted per day as a function of time. The similarity between Equation (3) for the rate of excretion of plutonium and Equation (9) for radium is evident.

A better way of comparing the excretion and retention of substances for which the functions are known is to compare their coefficients of elimination (i.e., the fraction of the total retained body burden excreted per day).

Norris and co-workers[8] derived the coefficient of elimination by dividing Equation (8) by Equation (5), as follows:

$$\frac{-\frac{dR_t}{dt}}{R_t} = \frac{Abt^{-(b+1)}}{At^{-b}} = \frac{b}{t} = 0.52t^{-1} \qquad (10)$$

A comparable calculation of the coefficient of elimination of plutonium gives

$$\frac{Y_{u+f}}{R_t} = 8.5 \times 10^{-3}t^{-1} \qquad (11)$$

Because of the uncertainties in the constants for the excretion equation (of the order of 10%), the above expression was derived empirically by solution of the excretion and retention equations using various values for t up to 10^4 days. These values were plotted and Equation (11) obtained by a least squares fit. The fitted curve was found to have a slope approximately equal to -1. It may be shown mathematically that the ratio of excretion rate to retention may be represented by an infinite series in which t^{-1} appears in the first term and succeeding terms may or may not be neglected, depending on the absolute values of c and a.

Comparison of the coefficients of elimination for radium and plutonium shows that the fractional rate of elimination of the retained body burden of plutonium is only 0.016 that of radium, even though the fractional rate of excretion on the basis of injected dose appears to be significantly larger at later times.

It is possible also to develop expressions for coefficients of urinary and fecal elimination in the manner used in Equations (10) and (11) when expressions for the rates of excretion are known. The specific expressions for the coefficients of elimination of plutonium, based on the excretion data shown in Fig. 3 (ref. 6) for the first 138 days, are as follows:

$$\frac{Y_u}{R_t} = 2.3 \times 10^{-3}t^{-0.76} \qquad (12)$$

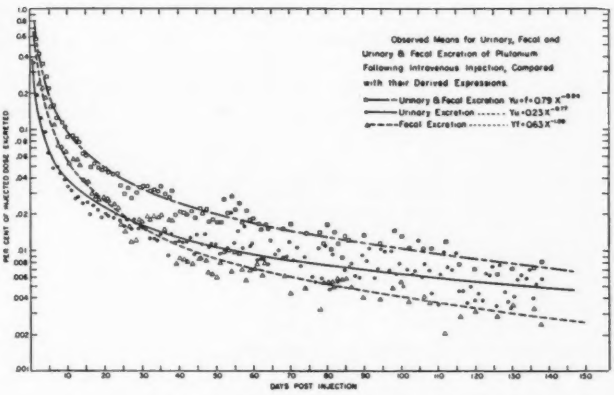

Fig. 3.
Urinary, fecal, and urinary plus fecal excretion of plutonium (over 138 days) administered intravenously to man.

$$\frac{Y_f}{R_t} = 6.2 \times 10^{-3} t^{-1.08} \qquad (13)$$

where $\frac{Y_u}{R_t}$ and $\frac{Y_f}{R_t}$ represent the fraction of the retained body burden excreted per day in the urine and feces, respectively. The slope constants for the coefficients of urinary and fecal elimination are not equal to each other and not eqeual to -1 (as in the case for the coefficient to total elimination shown by Equation (11), because the urinary to fecal excretion ratio is changing with time.

It is possible, however, to develop an equation for the variation of urinary to fecal ratio with time by dividing Equation (12) by Equation (13).

$$\frac{Y_u}{Y_f} = \frac{2.3 \times 10^{-3} t^{-0.76}}{6.2 \times 10^{-3} t^{-1.08}} = 0.37 t^{0.32} \qquad (14)$$

Solution of the above expression for t = 10 days and 10,000 days shows that the urinary to fecal excretion ratio for plutonium varies from 0.37 to 7 when extrapolated over a period of about 30 years.

The above treatment of the relation between excretion and total body burden of plutonium and radium provides a general method of approach to the problem of the internal radiation hazard associated with body deposition of radioactive materials when the excretion and retention functions cannot be expressed as single exponentials over the entire period of interest. From either excretion or retention data, it is possible to develop expressions for the retention and excretion functions and the co-efficient of elimination of any systemically-deposited radioactive material. These expressions provide a basis for the determination of total exposure and/or retained dose from excretion analysis and a knowledge of the exposure conditions. They also provide a basis for the calculation of maximum permissible levels.

Determination of Body Burden

IF THE EXPRESSIONS for the fecal or urinary excretion of any radioactive material is known, it is possible to determine the degree of exposure from excretion analyses. In the following discussion the expressions developed from the data given in Fig. 2 are used to demonstrate general methods for the determination of body burden from urine analyses following single acute, variable chronic and chronic invariant exposure, when the urinary excretion fails to follow a simple exponential pattern.

Determination of body burden following single acute exposure occurring at known time. Following a single acute exposure occurring at a known time the body burden of plutonium (D_E) at the time of exposure may be calculated from the assay of a 24-hour urine specimen collected t days later using Equation (2). If

$$Y_u = 0.002 t^{-0.74}$$

and

$$Y_u = \frac{U}{D_E}$$

where U is the amount of Pu found in a 24-hour urine sample at time t, then

$$D_E = 500\ U t^{0.74} \qquad (15)$$

Substitution of the proper values for t and U gives the total body burden at the time of exposure in whatever units (c/m, d/m, μc, or μg) are used to express U. Likewise, the retained body burden D_R at time t following a single acute exposure

may be calculated from the coefficient of urinary elimination given by Equation (12), since

$$\frac{\frac{U}{D_E}}{R_t} = \frac{Y_u}{R_t} = 2.3 \times 10^{-3} t^{-0.76}$$

then

$$D_R = R_t D_E = 435 U t^{0.76} \qquad (16)$$

in which the retained body burden is again expressed in the same units as U.

Determination of body burden following variable chronic exposure of known duration. The exposure dose received by an individual as a result of chronic variable exposure of known duration (i.e., the time worked since the last negative urine assay) may be approximated from the assay of a single 24-hour urine specimen by the same expression used for acute exposure occurring at known time. See Equation (15). One may assume that the individual obtained all of his body burden on the first day of exposure in which case t becomes the elapsed time from the beginning of work to the time of collection of the urine sample.

Unless the individual actually did accumulate his body burden on the first day of work, such an estimate will be too high. One may assume also that the body burden was obtained on the last day of work in which case t becomes the elapsed time between the last day of work and the time of collection of the urine specimen. In this case the estimate may be too low. One may also average the results obtained on the basis of the two assumptions made above. The average result, of course, has the greatest chance of carrying the smallest error.

A somewhat more exact method of estimating the exposure dose following chronic variable exposure is based on the assay of two 24-hour urine samples collected sufficiently far apart (with no exposure in between) to give significantly different results.

This method is based on the assumption that the exposure dose may be represented by a single *effective* dose occurring at some *effective* time intermediate to the limits of exposure.

If D_E is taken as the *effective* dose then the radioactivity excreted in the first urine sample collected q days after the *effective* exposure is

$$U_q = 0.002 D_E q^{-0.74} \qquad (17)$$

and the radioactivity in the second urine sample taken q + a days after the *effective* exposure is

$$U_{q+a} = 0.002 D_E (q+a)^{-0.74} \qquad (18)$$

Dividing Equation (17) by Equation (18) and solving for q gives

$$q = \frac{a}{\left(\frac{U_q}{U_{q+a}}\right)^{1.35} - 1}$$

q then is the effective time of exposure, and its substitution in Equation (17) gives the *effective* dose, D_E, as follows:

$$U_q = 0.002 D_E \left[\frac{a}{\left(\frac{U_q}{U_{q+a}}\right)^{1.35} - 1} \right]^{-0.74}$$

$$D_E = 500 U_q \left[\frac{a}{\left(\frac{U_q}{U_{q+a}}\right)^{1.35} - 1} \right]^{0.74} \qquad (19)$$

The above expression gives an approximation of the body burden at time q. The body burden is given in the same units as U_q and U_{q+a} and is expressed as a single *effective* dose occurring at some effective time intermediate to the limits of exposure.

A similar treatment of the problem of determining retained body burden following chronic variable exposure can be made starting with the coefficient of urinary elimination expressed by Equation (12).

Determination of body burden following chronic invariant exposure. Chronic invariant exposure to radioactive materials might be expected to occur under conditions where air concentrations are rigidly controlled, the work is highly routine and the nature of the material being worked with is such that it is more or less uniformly distributed throughout the atmospheric environment (as for example, a radioactive gas).

Although Equation (2) for the urinary excretion rate of plutonium is used as a basis for the following theoretical treatment, it is probably unrealistic to expect the results to have much practical applica-

tion to plutonium processing, where the material is not usually distributed uniformly throughout the working environment.

Starting with the equation for the urinary excretion rate of plutonium following a single dose Equation (2)

$$\frac{Y}{D_E} = Y_u = 0.002t^{-0.74}$$

and letting m = time of exposure in days, n = days from the beginning of an exposure to the time a urine analysis is made with n > m (preferably by more than 10 days), and assuming a constant daily exposure D_m, then the counts per minute in the urine excreted on day n is:

$$U_n = .002\ D_m\ [n^{-0.74} + (n-1)^{-0.74} + (n-2)^{-0.74} + (n-m+1)^{-0.74}].$$

The bracketed term is similar to the infinite series r^t with the limiting values (n-m+1) and (n) and t = -0.74. It may be evaluated by the following equation:

$$U_n = .002\ D_m \int_{T_0}^{T_1} (T_2 + Z)^{-0.74}\ dZ$$

where $T_0 = \frac{1}{2}$, $T_1 = m + \frac{1}{2}$, and $T_2 = n - m$, the value $\frac{1}{2}$ is used because the series diverges badly as $T_2 \to 0$ and n = m. Solution of the above expression gives

$$U_n = \frac{.002}{0.26} D_m$$

$$[(T_2 + T_1)^{0.26} - (T_2 + T_0)^{0.26}]$$

or

$U_n = 130\ D_m [(n + \frac{1}{2})^{0.26} - (n-m+\frac{1}{2})^{0.26}]$. Since ${}^TD_m = m\ D_m$ = total exposure dose, then

$${}^TD_m = \frac{130\ m\ U_n}{(n + \frac{1}{2})^{0.26} - (n - m + \frac{1}{2})^{0.26}} \quad (20)$$

Evaluation of the series shows that the formula is good to two parts in 50 for r = 1, and to better than one part in 1000 for r > 5.

A specific example of the application of the above dosage calculation is given below, using the expression for seven exposure days per week. In fact, the seven-day exposure formula may be valid for either the five or six-day week. Such would be the case if one considers that absorption from the lung is the primary source of contamination and that the equilibrium between the alveolar and blood plutonium concentration is not radically altered by the one or two-day period of no exposure each week.

For purposes of presenting a specific example one may assume the following conditions:

Duration of exposure (m) = 330 days
Duration of time from beginning of exposure until urine sample taken (n) = 360 days
Counts per minute of urine sample (U_n) = 2 c/m
The total body dose ${}^TD_m$ may be calculated from the formula:

$${}^TD_m = \frac{130 \times m \times U_n}{(n + \frac{1}{2})^{0.26} - (n-m + \frac{1}{2})^{0.26}}$$

On substitution:

$${}^TD_m = \frac{130 \times 330 \times 2}{(360.5)^{0.26} - (30.5)^{0.26}} = \frac{8.58 \times 10^4}{2.19} = 3.9 \times 10^4\ c/m$$

Assuming a 50% counting geometry was used (1 μg = 7×10^4 c/m)

$${}^TD_m = 0.56\ \mu g.$$

TABLE II.
RESULTS OF URINE ASSAYS AND NOSE SWAB COUNTS CONDUCTED ON LOS ALAMOS PLUTONIUM OPERATORS SHOWING POSITIVE EXPOSURE

Case Code	Average Date of Exposure	Estimated Body Burden μg (±50%)	Total No. High Nose Swabs
W.G.	June 1945	1.3	24
W.B.	May 1945	1.2	37
D.D.	June 1945	1.2	55
D.W.	June 1945	1.0	32
W.A.	July 1945	1.0	22
G.F.	June 1945	1.0	28
R.D.B.	July 1945	0.8	24
F.C.	June 1945	0.7	60
H.R.	Aug. 1945	0.7	14
W.S.	Aug. 1945	0.6	9
T.M.	Late 1944	0.5-1.0	1(a)
H.L.	Aug. 1945	0.5	8
T.E.	July 1946	0.4	6
R.A.B.	July 1945	0.4	23
M.W.	Aug. 1945	0.3	6
D.K.	Aug. 1945	0.3	28
D.H.	Aug. 1945	0.3	22
K.E.	Oct. 1945	0.3	3
J.C.	Sept. 1945	0.3	8
J.B.	July 1945	0.3	8
J.A.	Oct. 1945	0.3	11
E.R.	July 1945	0.2	2
C.H.	July 1945	0.2	7
N.D.	Late 1944	0.1-0.5	3(a)
J.O.	Sept. 1945	0.1	8
C.D.	July 1945	0.1	4
A.B.	Sept. 1945	0.1	8

(a) Incomplete records were available for these cases.

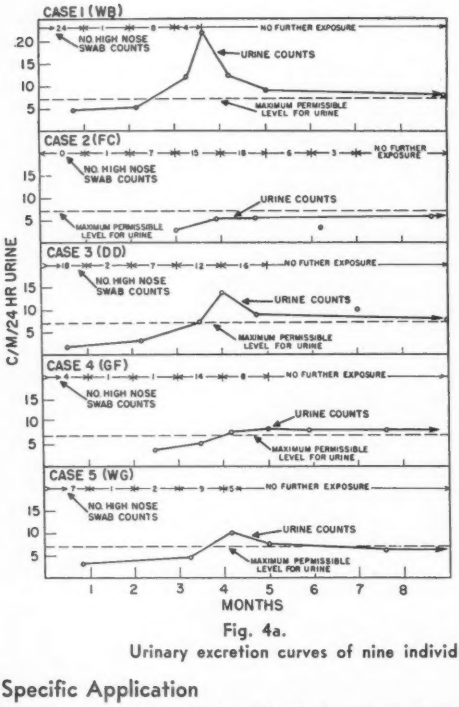

Fig. 4a.

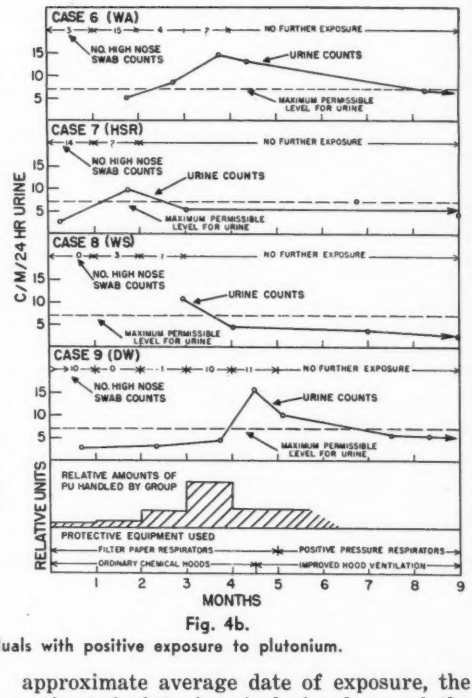

Fig. 4b.

Urinary excretion curves of nine individuals with positive exposure to plutonium.

Specific Application

THE LOS ALAMOS Scientific Laboratory has been processing relatively large quantities of Pu^{239} since 1944. It was essential, therefore, that methods be developed to determine exposure of personnel. The assay of 24-hour urine samples for alpha activity, although difficult and time consuming, proved feasible.

From 1944 to 1950 over 6000 urine analyses were made on persons working with plutonium.[8] Urine assays showed that 27 of the persons examined excreted measurable amounts of plutonium which indicated body burdens ranging from about 0.1 to 1.3 μg. All positive exposures occurred during the period 1944-1946. These data were supplemented by data collected by the nasal swab technique,* the purpose of which was to detect qualitatively whether or not individuals had been exposed to the inhalation of contamination. Table II shows the approximate average date of exposure, the estimated plutonium body burden, and the total number of high nose swab counts. It should be emphasized that the estimated body burdens are perhaps not accurate to greater than $\pm 50\%$ except in nine cases for which repeated urine assays were obtained. The rather large error associated with the estimates resulted from the extremely low alpha activities being detected. Assuming a urinary plutonium excretion rate of 0.01% of the body burden per 24 hours, the detection of 0.1 μg of systemically bound plutonium requires the determination of 1 c/m in a 24-hour sample of urine. Nine of the positive exposures occurred in the same process which involved working with water-soluble plutonium salts in dilute solutions and under conditions favorable to the production of a fine spray. Urinary excretion curves for these nine individuals are shown in Figs. 4a and 4b. These data indicate beyond doubt that they had accumulated positive plutonium body burdens because the analyses were repeated several times. Case 1 (W.B.) shows the typical urinary excretion curve following

*The nasal swab procedure, in brief, consists of swabbing the external nares and subsequently counting the nose swab for radioactivity. The method is applicable not only to plutonium but to any particulate radioactive material. Using this technique the presence of radioactive material in the nasal vestibule can be detected.

what may be considered a relatively acute exposure. The urinary excretion rate rose rapidly to approximately 23 c/m per 24-hour sample, at which time he was removed from further exposure. Upon being removed from from further exposure his urine assay dropped sharply and began to show a plateau after 30-60 days. Cases 2 (F. C.) and 4 (G. F.) show urinary excretion curves which may be considered characteristic of prolonged chronic exposure. These individuals did not show sharp peaks in their urinary excretion and upon removal from exposure their urine assays did not drop sharply.

The curves in Figs. 4a and 4b, further emphasize the fact that the positive urine values in the nine unquestionable cases were preceded by or occurred simultaneously with periods of high nose swab counts. Because some persons were more cooperative than others, no quantitative significance can be attached to the absolute numbers of high nose swabs for the various individuals during any given period. Both the urine assays and the number of high nose swab counts correlate roughly with the scale of relative amounts of plutonium processed per month by this group. These data suggest that the nine operators accumulated their plutonium burdens largely through respiratory exposure.

TABLE III.
COMPARISON OF FECAL AND URINARY EXCRETION OF PLUTONIUM BY LOS ALAMOS WORKERS IN RELATION TO MODE OF EXPOSURE

Subjects	Type of Exposure	Approximate Time after Exposure (months)	Feces (c/m/24 hr)	Urine (c/m/24 hr)*
Average of 25	No exposure	—	0.9 ± 0.4	0.7 ± 0.4
D. L.	Slight, general	1	0.7	1.1
S. H.	Moderate, general	1	25	1.0
V. S.	High, general	6	68	0.9
W. S.	Dry Box Explosion	6	7	0.7
I. M.	Dry Box Explosion	6	23	0.7
J. C.	Burning Pu Metal	6	2	0.8
J. D. C.	Burning Pu Metal	6	19	0.5
E. Z.**	Burning Pu Metal	½	1190	1.3
E. F.	Burning Pu Metal	½	70	0.8
L. D. R.	Burning Pu Metal	½	950	0.6
T. A. E.**	Spray of $PuO_2(NO_3)_2$	1	3400	5.0
F. C.**	Spray of $Pu(NO_3)_4$	9	196	2.6
W. A. B.**	Spray of $Pu(NO_3)_4$	10	130	7.3
D. D.	Spray of $Pu(NO_3)_4$	12	21	4.9
W. B. G.**	Spray of $Pu(NO_3)_4$	11	237	4.3
G. F.	Spray of $Pu(NO_3)_4$	10	24	3.6

* Counts of less than one have no statistical significance.
** Used to calculate values for lung burden given in Table IV.

Radioactive Material in the Lung

IT MUST be emphasized that urinary excretion analyses do not measure unabsorbed radioactive material deposited in the lung and cannot, therefore, be directly applied to the determination of lung exposure. Urinary excretion is an index of the "systemic burden" only, i.e., the amount of material that has been taken into the blood stream and subsequently deposited in the tissues.

Attempts were made at the Los Alamos Scientific Laboratory to apply urinary to fecal ratios as a measure of lung burden. If the urinary to fecal ratio as a function of time after exposure, expressed in Equation (14), is a measure of the relative amounts of systemically-deposited plutonium excreted via urine and feces, then extremely low ratios (high fecal excretion) would indicate the presence of plutonium in the feces that must have been excreted from the lung by ciliary elimination and subsequently swallowed. The data in Table III show the urinary and fecal excretion of plutonium by Los Alamos workers in relation to their mode of exposure. Instead of the urinary to fecal ratios being in agreement with the values indicated by Equation (14) they were on occasion as low as 10^{-3}. Undoubtedly these data establish qualitatively the presence of a lung burden in several of the exposed subjects.

The quantitative estimation of lung burden from excretion analyses as well as the calculation of lung exposure from nonabsorbed radioactive materials necessitates prior knowledge of the kinetics of lung retention and elimination. The problem appears almost hopelessly complex. Lung retention and elimination have been shown to be dependent on particle size,[9-15] solubility,[16] hygroscopicity,[17] wetting,[12] concentration,[10-12] respiration rate,[10-12] particle density,[12-15] flocculation,[15] and on the chemical nature of the material inhaled.[18,19] The aspects of dust retention in the lungs of man are reviewed by Drinker and Hatch.[20]

Insufficient data are available to permit

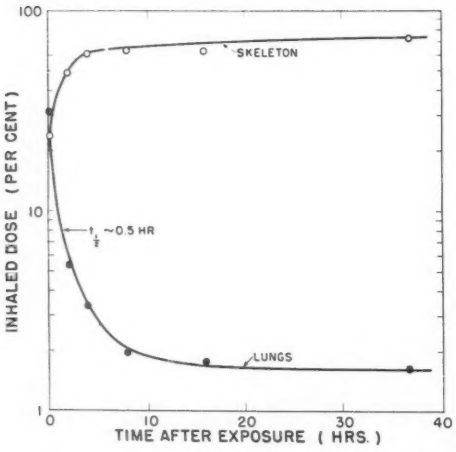

Fig. 5.
Distribution of Sr as a function of time after inhalation of a $Sr^{89}Cl_2$ aerosol (rats).[18]

satisfactory elucidation of the kinetics of lung retention and elimination for a single radionuclide under any specific set of conditions. Some data, which may permit generalization, are available from the excellent work of Abrams *et al.*[18,19] and Scott *et al.*[21] on the fate and deposition of plutonium and various fission products inhaled as aerosols by rats.

Figs. 5, 6, and 7 are taken from the work by Abrams *et al.*[18,19] to illustrate the typical types of elimination and distribution patterns found following inhalation of aerosols. Their data which were reported on the basis of amount retained in the lungs as 100% have been converted to inhaled dose assuming 75% retention. This assumption may be in considerable error because of the very small particle sizes employed ($<1\ \mu$). Fig. 5, for a $Sr^{89}Cl_2$ atomized aerosol, shows the behavior of a soluble material. The half-time in the lung was extremely short (hours or less) and there was equally rapid appearance of the radioactivity in the organ of deposition, in this case the skeleton. The process involved is apparently direct solution in the body fluids and rapid entrance into the system. Fig. 6 shows the very different behavior of an insoluble material, in this case a PuO_2 smoke of fine particle size, produced in an electric arc. The half-time in the lung was

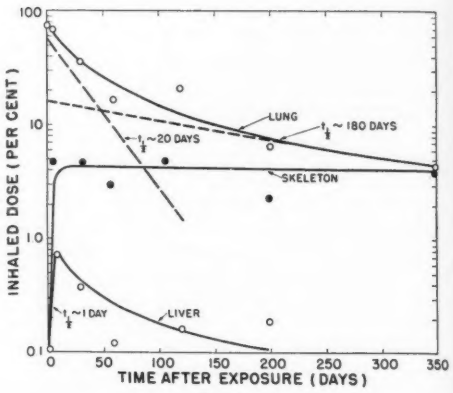

Fig. 6.
Distribution of Pu as a function of time after inhalation of a PuO_2 aerosol (rats).[19]

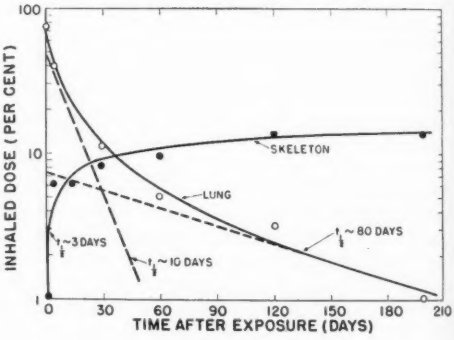

Fig. 7.
Distribution of Ce as a function of time after inhalation of a $Ce^{144}O_2$ aerosol (rats).[18]

much longer, components of roughly 20 and 180 days seem indicated, and a small amount ($<10\%$) rapidly reached the liver and skeleton. This very rapid entry of a small amount of supposedly insoluble material was always evident. In fact, the major amount of material entering the systemic circulation did so within a matter of hours or a few days. Direct solution, phagocytic solution, or direct passage of very fine particles into the body fluids before flocculation may provide an explanation. That physical transport out of the lung is involved is confirmed by the excretion data. During the period from 50 to 150 days the fecal excretion was 100 times the urinary excretion. An intermediate case is illus-

trated in Fig. 7 for an arced aerosol of Ce^{144}. The half-times observed were very similar to those found with PuO_2, but in this case there was rapid significant entry into the skeleton. Fecal to urinary excretion ratios were again very high compared with those found following intramuscular or intravenous injection, so removal from the lung must be by ciliary action and subsequent swallowing. In this case there may be significant uptake into the system from the gut.

The long half-times associated with ciliary transport are confirmed by the studies of Marinelli *et al*[22] on $RaSO_4$ accidentally inhaled by humans. They find lung elimination times of from 30 to 140 days with an average half-time of about 120 days over the first year.

It is clear that the elucidation of the kinetics of lung retention and elimination is an extremely complex problem and requires much detailed information on the fate of nuclides of interest as a function of chemical form, particle size, etc. However, even with the preliminary data now available certain generalizations are suggested:

(1) If the material is truly soluble in body fluids (i.e., $Sr^{89}Cl_2$), removal from the lung is essentially instantaneous and no lung hazard persists. In this case urinary excretion data may be used to determine total body burden.

(2) "Insoluble" particles (i.e., PuO_2) are removed with half-times of a few weeks and about six months presumably by two different mechanisms. Both mechanisms apparently involve transport through the GI tract. About 5% to 10% of the inhaled dose may enter the blood stream rapidly and constitute the systemic burden.

(3) "Slightly soluble" particles act in general like particles of insoluble materials, except a higher percentage may enter the systemic circulation and contribute to the systemic burden.

(4) While urinary excretion data are a measure of systemic burden, fecal excretion may be quantitatively related to pulmonary elimination of relatively insoluble materials and to the burden of such materials deposited in the lung. Beyond 10 days after exposure the lung excretion data given in Fig. 6 may be represented by a single hyperbolic function

$$C_L = 6.4t^{-0.8} \qquad (21)$$

where C_L is the fraction of the intial dose remaining in the lung and t is the time in days.

Since the amount excreted from the lung after this time appears in the feces, the negative derivative of this expression gives the fecal excretion rate as

$$-\frac{dC_L}{dt} = E_f = 5.12t^{-1.8} \qquad (22)$$

where E_f is the rate of fecal excretion in fraction of the lung dose excreted per day.

The urinary to fecal excretion ratio $\left(\frac{Y_u}{Y_f}\right)$ following intravenous injection is given by Equation (14). This ratio is an index of the excretion pattern for systemic plutonium and a decrease in the ratio at any time after exposure reflects the presence in the feces of plutonium from a nonsystemic source, most likely the lung.

It should be possible, therefore, to estimate both the systemic burden and the lung burden from the assay of urine and fecal samples taken at known times after exposure. Starting with the expression for the systemic urinary to fecal excretion ratio (Equation (14))

$$Y_f = \frac{Y_u}{0.37}t^{-0.32}.$$

If the total fecal count on day t after exposure is Y_{f_t}, and the total urine count is Y_{u_t}, then the portion of the total fecal activity (Y_{f_L}) due to lung contamination is given by the following expression:

$$Y_{f_L} = Y_{f_t} - \frac{Y_{u_t}}{0.37}t^{0.32} \qquad (23)$$

and it follows from Equations (22) and (23) that

$$C_L = \frac{Y_{f_L}}{E_f} = \frac{Y_{f_t} - \frac{Y_{u_t}}{0.37}t^{0.32}}{5.12t^{-1.8}} \qquad (24)$$

TABLE IV.
PLUTONIUM LUNG BURDEN IN LOS ALAMOS WORKERS WHEN DERIVED FROM SYSTEMIC BURDEN AND FROM URINARY TO FECAL EXCRETION RATIOS

		Lung Burden	
Subjects	Systemic Burden (μc)	Systemic Burden X10 (μc)	From Urinary/Fecal Ratios (μc)
F. C.	0.11	1.1	1.2
E. Z.	0.004	0.043	0.027
T. A. E.	0.035	0.35	0.28
W. A. B.	0.086	0.86	0.72
W. B. G.	0.094	0.94	1.1

where C_L is the lung burden at 10 days post-exposure expressed in the same units used for Y_u and Y_f. Since at 10 days ~10% of the original lung burden has entered the systemic circulation ($t^{\frac{1}{2}} \cong 1$ day) the amount in the lung at time of exposure is

$$\frac{C_L}{0.9} = 1.1\ C_L . \qquad (25)$$

If the data in Fig. 6 are applicable and approximately 10% of the lung burden is absorbed within a few days, the amount of material in the lung at the time of exposure may be estimated by multiplying the systemic burden by ten. Table IV shows a comparison of the lung burdens of five of the individuals listed in Table III, when calculated from the systemic burden and from the urinary to fecal excretion ratios. The agreement between the values derived by the two different methods is surprisingly good.

Because of the extreme complexity of the problem, the lack of specific data and the need for a basis for calculating maximum permissible air concentrations from lung exposure, a general model for the fate of radioactive particles in the lung has been proposed.* The model is based largely on the data of Abrams *et al.*[18,19] and Scott *et al.*[21] for rats and completely ignores most of the factors mentioned earlier as affecting particle retention in the lung. The assumption is made that the particle size distribution of the inhaled aerosol is such that the total lung retention is 75% of the inhaled dose. It is quantitative only to the extent the specific conditions of exposure coincide with the general pattern on which the model is based.

According to the model shown in Fig. 8, when 100 particles are inhaled, 25 are exhaled without deposition in the respiratory system. These do not contribute to the production of a health hazard. Of the 75 particles deposited in the lung, 50 deposit in the upper bronchial tree and are excreted by ciliary action and swallowed. The half-time of elimination of these 50 particles is ~20 days regardless of solubility. Of the 50 particles entering the gut from the lung, 10-20% of the soluble particles, <0.5% of the slightly soluble and <0.01% of the insoluble materials, may be absorbed and end up in the system. The 25 particles remaining in the lung are assumed to be deposited on the alveolar surfaces. If these particles are "insoluble" 15 (15% of the originally inhaled dose) are phagocytized or otherwise removed up the bronchial tree and eliminated via the gut with an elimination half-time of about six months. The other remaining 10% of the material passes through the alveolar wall into the systemic circulation with a half-time of a few days at most.

If the 25 particles in the alveoli are "slightly soluble," the kinetics of retention and excretion may be essentially the same as for "insoluble particles." A slightly higher percentage may be absorbed and contribute to the systemic burden and a slightly lower percentage may be removed by bronchial elimination with a somewhat shorter half-time. If the particles are soluble, all 25 are absorbed in the systemic circulation with a half-time of an hour or so.

The data in Fig. 5 for a soluble aerosol ($Sr^{89}Cl_2$) do not fit the general pattern. This may be explained on the basis of the exceedingly small particle size (0.1 μ) which would result in much lower deposition in the upper bronchial tree and much higher in the alveoli.[15]

It should be emphasized that the numbers given in the model are only crude generalizations based on obviously inadequate data and future research should be directed toward obtaining specific numbers for specific nuclides.

*AEC Harriman Conference, Harriman, New York, 1953. Participants, K. Z. Morgan, J. G. Hamilton, W. H. Langham, L. D. Marinelli, and others. Many of the features of the model as shown were added by the author.

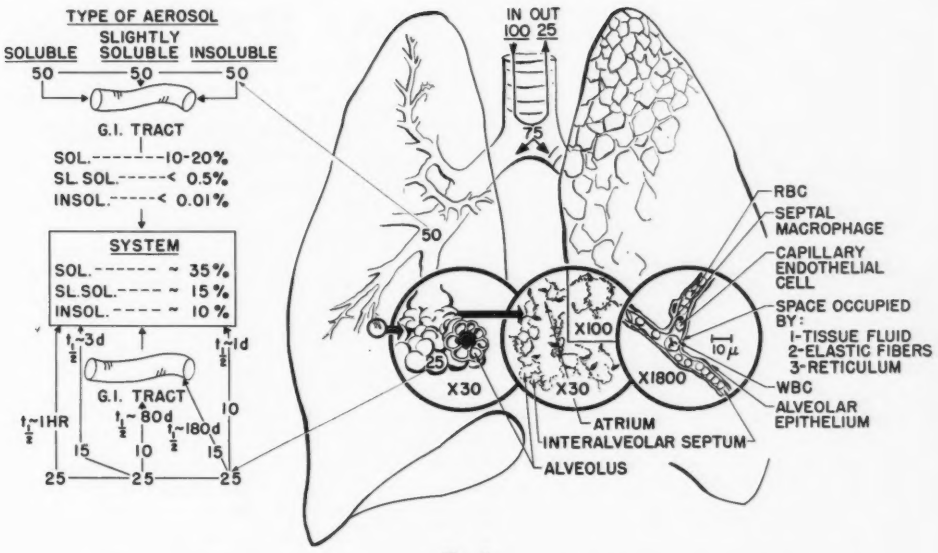

Fig. 8.
General model for the retention, distribution, and excretion of inhaled radioactive aerosols.

The model poses two different radiation hazards: (1) direct radiation of the lung by the deposition of 75% of the inhaled radioactivity, taking into account the respective abundances and the half-times of the three components of the elimination process, and (2) the systemic radiation hazard produced by absorption and subsequent deposition of a fraction of the inhaled dose in the tissues. The model may be of some value in estimating (in the general case) the magnitudes of these hazards from isotopes for which inadequate data exist.

Acknowledgment

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National Noise Abatement Symposium

THE SEVENTH ANNUAL National Noise Abatement Symposium will be held at the Sherman Hotel, Chicago, on October 11-12, 1956. The 1956 NNAS is sponsored by Armour Research Foundation of Illinois Institute of Technology, Acoustical Society of America, American Society of Safety Engineers, National Noise Abatement Council, American Society of Planning Officials, American Industrial Hygiene Association, and Acoustical Materials Association.

This year there will be 14 papers as follows: Estimating Noise Levels from Jet Aircraft—ADONE C. PIETRASANTA, Engineer, Bolt, Beranek and Newman, Inc.; Environment for Measuring Noise—HENRY B. KARPLUS, Associate Physicist, Armour Research Foundation; Materials and Techniques for Damping Vibrating Panels—RICHARD N. HAMME, Research Physicist, Engineering Research Institute, University of Michigan; Noise Reduction in Pumps and Pump Systems—NORMAN L. MEYERSON, Manager, Research and Development Section, Worthington Corporation; Noise Control by Phase Control of Extended Sources—DR. G. J. THIESSEN, Principal Research Officer, Canadian National Research Council; Acoustical Design of Enclosures for Power Transformers—DR. THOMAS NORTHWOOD, Head, Building Physics Section, Canadian National Research Council; Audiometers and Their Use—RALPH ALLISON, Allison Laboratories, Inc.; A Mobile Laboratory for Group Hearing Tests—DR. JEROME R. COX, Research Associate, Central Institute for the Deaf; Legal Aspects of the Hearing Loss Problems—NOEL SYMONS, Attorney, Brown, Kelley, Turner and Symons; Problems of Industry in a State with Hearing Loss Compensation Laws—ROBERT A. EWENS, Attorney, Executive Vice-President, Wisconsin Manufacturers Association; Acoustical Engineering Principles for Noise Reduction—WILLIS M. REES, Product Development Engineer, Owens-Corning Fiberglas Corporation; Retaining High Sound Transmission Loss in Industrial Plants—GEORGE L. BONVALLET, Manager, Noise Control Division, Rysdon Products Company; Office and Factory Applications of Partial Enclosures—DWIGHT BISHOP, Acoustics Engineer, Convair Division, General Dynamics Corporation; Noise Control for Offices Located Near Production Machines and Mechanical Equipment Spaces—LAYMON N. MILLER and IRA DYER, Senior Engineers, Bolt, Beranek and Newman, Inc.

The registration fee is $15.00, which covers the technical sessions, luncheons on both the 11th and 12th and a copy of the proceedings. Inquiries should be addressed to GUY J. SANDERS, Armour Research Foundation, 10 West 35th Street, Chicago 16, Illinois.

Criteria for an Evaluation of Noise Problems

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THE QUEST for standards or criteria relating to the effects of noise on man has been going on for many years. A perusal of the literature reveals many attempts to establish levels below which exposed personnel will not develop hearing loss. There are also other kinds of criteria which have been suggested. A complete review of this problem requires consideration of these several criteria related to such things as the possible effects of noise on behavior (annoyance); loss of hearing; speech communication and other non-otological effects. Each of these requires a quite different approach. We must first define what we are trying to accomplish in the establishment of noise standards. Because of the fact that the effects of noise differ in many respects from the toxicological problems with which we are so familiar it would be well to establish a base upon which to develop our philosophy about noise criteria.

There are many ways in which the so-called noise problem differs from our other industrial hygiene problems. In the first place, there are at least four different kinds of effects to be taken into consideration. We shall see that the difference between a standard for speech communication in a conference room and the kind of criterion which is being proposed to prevent occupational loss of hearing is substantial. Second, gradual loss of hearing over the years may be a normal result of aging. Most other occupational diseases do not produce a result identical to normal aging processes. Third, there are many causes of cochlear damage both physical and chemical in addition to noise. Fourth, the noise levels in our non-industrial environment have been increasing steadily during the past twenty-five years. Fifth, an appreciable segment of the population has deviation from normal hearing from many possible causes. All of these things serve to confuse our thinking about criteria for noise.

It is important then that we consider separately each of the kinds of effects which noise may have on people. Standards must then be selected for each specific problem which needs to be solved.

Effects of noise on behavior is the phrase applied by Kryter[1] to the various possible psychological effects of noise exposure. This is an extremely complex and nebulous phase of the noise problem. Such factors as annoyance and irritability are related not only to the intensity and frequency (physical characteristics) of the noise, but also to the time pattern, the environment and the physical and mental attitude of the subject. Many attempts have been made to relate these non-auditory effects to such things as efficiency, production, fatigue, absenteeism, turnover, etc., in industry. There have been several studies made to evaluate these effects, particularly in industry and in military operations. Many of these are discussed critically by Kryter and, therefore, will not be covered here.

One of the problems in such studies involving human response to environment, is the virtual impossibility of defining or measuring the many variables. In the environment itself such factors as illumination, ventilation, physical surroundings, temperature and humidity are difficult to evaluate and their independent effects difficult to determine. Superimposed on this are the even greater variables of the physical and mental attitudes of the individuals involved and the complex inter-relationship between various individuals in a group. It has been found also, particularly in the studies of Weston and Adams on the work performance of weavers in the textile industry in England[2] that motivation may

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have an important bearing, particularly early in an experiment.

In addition to field studies of groups of individuals, there have been several attempts to study under laboratory conditions such things as effects of noise on reaction time, intelligence test scores, as well as mental and muscular work, using human subjects. In most of these experiments very small numbers of subjects were used, limited conditions set up and inconclusive results obtained.

From the research which has been reported, there are many indications that noise may have some effects on behavior—in some cases deleterious and in some cases beneficial. The best that can be said at the moment is that there are tantalizing indications as to the effects of noise on a man's behavior pattern, but at this time no precise conclusions can be drawn.

One of the most serious annoyance problems in the industrial noise field is probably

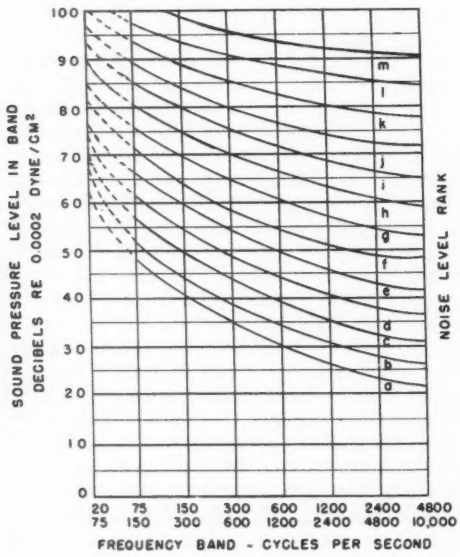

Fig. 1.
Family of curves used to determine the noise level rank for residential noise. The spectrum of the noise is plotted as sound pressure levels in octave bands of frequency. The highest zone into which the spectrum protrudes is designated as the noise level rank. (From Stevens, Rosenblith and Bolt.)

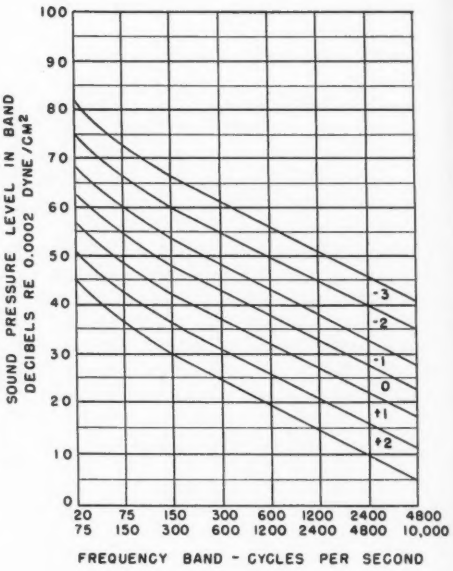

Fig. 2.
Family of curves used to determine the correction number for background noise. The spectrum of the ambient background noise is plotted as sound pressure levels in octave bands of frequency. The zone in which the major portion of the noise spectrum lies designates the correction number to be applied for background noise. (From Stevens, Rosenblith and Bolt.)

in neighborhoods surrounding industrial operations, airports and highways. The annoyance of neighbors can have serious repercussions in some industrial operations. An important phase of this problem is related to night operation, for the most important factors of annoyance are present —-there is a low background noise at a time when traffic and other "acceptable" noises are reduced. This causes frustration because of the desire to sleep and the inability to do anything about the distraction. This is not entirely a question of the physical character of the noise or its time pattern. A dripping faucet, barely heard, can keep one awake almost indefinitely. Here again, as in most annoyance problems, the physical and mental state of the victim are important factors.

How does one measure annoyance? Other factors than the intensity and frequency of the sound are much more important. The

best "instrument" for measuring this is the annoyed individual. If neighbors are annoyed and complain about an industrial noise, no technical noise studies are going to convince the sleepless complainer that the noise level of 50 decibels or even 40 decibels is within reasonable limits.

Stevens, Rosenblith and Bolt[3] have proposed a method of rating possible community reactions to various kinds of noise under different conditions. Their approach serves to emphasize the extreme complexity of the problem. They suggest a series of spectra for establishing a noise level rank (Fig. 1); a family of curves to determine a correction number for background noise (Fig. 2); correction numbers for daytime ambient noise levels in typical kinds of neighborhoods; correction numbers for repetitiveness of the noise, season of the year, time of day and previous exposure. From these numbers are compiled a "Composite noise rating." These ratings are then plotted against known community responses in several cases to produce a wide range curve for predicting community response (Fig. 3). It should be added that there are other factors which may also affect community response. In cases where a majority of the neighbors work at the offending plant, there are liable to be less complaints; a good plant public relations program can modify the response substantially; if the plant is also producing obnoxious air pollution or other annoyances, noise complaints may increase.

It should be obvious from this brief discussion that the most logical criterion for determing an annoying noise is—are people being annoyed?

Speech interference is a phase of industrial noise which is in part related to annoyance. In industry, the ability to communicate by speech is vitally important. It is essential in employee training, in giving and understanding orders, in giving warnings of danger and many other phases of plant operation. In addition, the inability to communicate can be annoying. As a generality it can be stated that hazardous noises generally produce speech interference, but noise which interferes with speech is not necessarily hazardous.

The degree of interference depends pri-

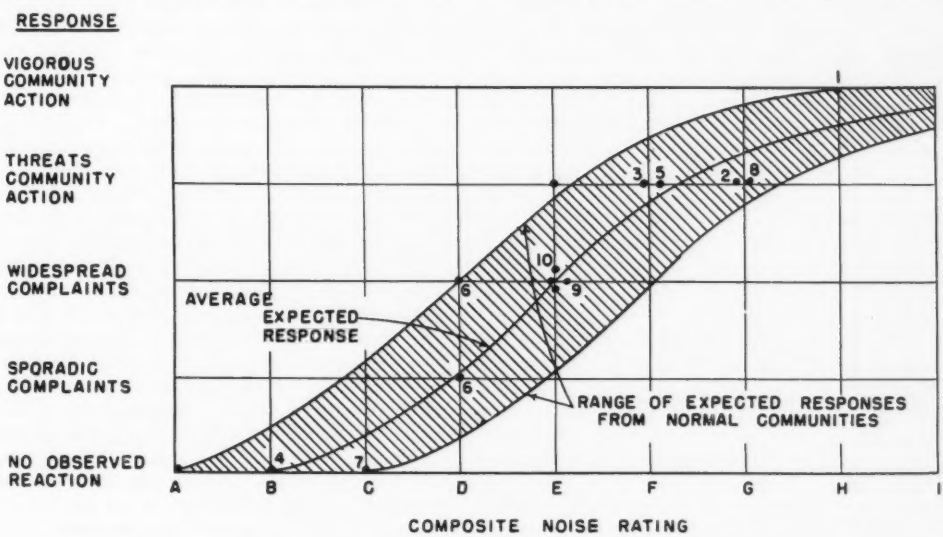

Fig. 3.

The wide curve shows the range of responses that can be expected from communities exposed to noises of increasing severity. The center curve is the average response. Community response is assessed along the ordinate. Each point represents a case history of neighborhood reaction to noise. (From Stevens, Rosenblith and Bolt.)

marily on two factors—the masking ability of the noise and the communication requirements of the environment. An evaluation of the masking quality of noise is based on sound levels in the bands which mask speech most effectively.

The phrase "speech interference level" (SIL),[4] suggested by Beranek, is a measure of the interfering effect of noise on the ability of two people to converse. It is defined as the arithmetic average of the sound levels, in decibels, in the three octave bands 600-1200, 1200-2400 and 2400-4800 cycles per second. The application of these values requires consideration of the distance at which conversation must be understood and the kind of voice (normal, raised, very loud, shouting) which can be used. Considerable judgment must be used in applying these data to actual conditions. The values are very different for different situations. For example (see Fig. 4) in a conference room where conversation must be understood at distances up to 10 feet or more in a normal voice, an SIL of 50 decibels may be too high, whereas 70 decibels may be satisfactory in an industrial plant where conversation may be carried on at distances of one foot or less. It should be borne in mind that these criteria were derived under laboratory conditions using the intelligibility of a large number of words. For practical plant application, the values could probably be increased slightly because of a more limited vocabulary and the possibility of increased intelligibility resulting from visual cues.

It should be noted that the values given are of a lower order of magnitude than those generally considered for damage risk criteria.

Damage to hearing is the problem of greatest significance in industrial operations. As activity in the study of noise has increased there has been more and more pressure for the establishment of some sort of damage risk criterion. The literature contains many guesses as to what this may be, but these are based more on logic than on any substantial evidence. One important fact which has emerged from the studies which have been made is that a single, over-all sound level measurement (20 to 10,000 cps) does *not* provide an adequate basis for the establishment of any criterion

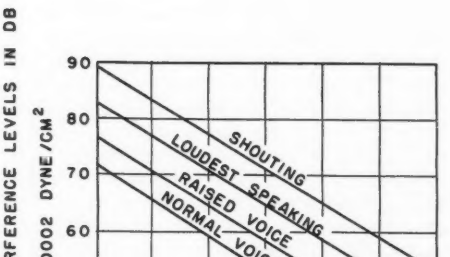

Fig. 4.
The relation of speech levels, distance, and noise in terms of the Speech Interference Level. The Speech Interference Level is the arithmetic average of the noise levels, expressed in decibels, in the three bands 600-1200, 1200-2400 and 2400-4800 cps. (From L. L. Beranek, Trans. Am. Soc. Mech. Engrs., 67, 97-100, 1947.)

or safe level. It has become obvious that the noise must be defined in narrower bands to judge the possible impact on the hearing of exposed people. This concept has been emphasized repeatedly by many authorities. Kryter[1] stated in 1950 "It is clear that *the spectrum of a noise must be analyzed before its deafening value can be estimated.*" (Kryter's italics). This concept has been re-stated by such authorities as Beranek,[4] Rosenblith and Stevens[5] and the exploratory sub-committee Z24-X.2 of the American Standards Association[6] has re-emphasized this point.

In establishing a damage risk criterion or a series of such criteria several factors are involved. The very words "damage risk criterion" imply that its purpose is to reduce the risk that an individual will suffer hearing loss. This, then, is a statistical approach. It is more or less forced upon us by the fact that there are so many other possible causes of loss of hearing and that a significant segment of our population has a deviation from normal hearing.

What are the factors which must be considered in setting up the kind of standards we are discussing? We should study and

understand several basic premises if we are to develop adequate, equitable criteria.

1. The criterion must be established in measurable perameters. It must be expressed in terms of sound pressure level and frequency. The distribution of energy through the audible spectrum is an important variable. It may be spread through the whole spectrum or it may be confined to relatively narrow bands. The band widths and distribution of the important components of a noise must be defined, since damage may be related to these factors.

2. The time of exposure must be specified. Consideration must be given to levels for continuous (throughout the work day) steady noise exposures; steady noise with intermittent exposure (periodic during the day); and single or very short exposure (corresponding to acute exposures in toxicology).

3. The time pattern of the noise will have an important bearing on criteria. The levels for repeated impact noise may be significantly different than for steady noise. Peak value, average value, ambient noise, and the interval between peaks are all significant.

4. The final values selected for damage risk criteria must be based on the physical factors given above and must then be related to the degree of deviation from normal hearing which is considered acceptable. In this latter category such factors as presbycusis and a definition of just what constitutes a hearing loss must be included.

5. Any standard must be supported by substantial agreement among authorities before it can be accepted. It is, therefore, of primary importance that any criteria which are proposed must be supported by a reasonable amount of valid data.

From a historical point of view let us examine what has taken place in attempts to arrive at a benchmark to be used in preserving the hearing of our industrial population. The era during the 1930's and 1940's appears to have been devoted largely to expression by various authorities of "curbstone opinions" as to a single number which supposedly represented a permissible noise level. It should be borne in mind that during this period of time, measurement techniques were crude and there were no data available on frequency distribution of various kinds of industrial noises. All of the numbers proposed during this time were admittedly without foundation and were always hedged with "ifs," "ands," and "buts." We can summarize this era by stating that reasonable evidence for any noise criterion was lacking. Thus we should relegate the guesses of the 30's and 40's to history and ignore them in all further discussions on this matter.

Perhaps the first attempt to provide a substantiated damage risk criterion was made by Kryter[1] in his classic monograph on "The Effects of Noise on Man." After a detailed and critical review of all available literature Kryter proposed, as a starting point, a criterion which took into consideration the fact that the ear has a nonlinear frequency response. His conclusions in the matter of "Maximum safe intensity level" are as follows:

"A fair, perhaps conservative, evaluation of the laboratory and industrial studies on stimulation deafness would seem to be that for long and intermittent exposures any frequency of sound (or narrow band not exceeding the critical width) that is 85 db or less above .0002 dynes/cm^2 will not cause any temporary or permanent deafness.

"The 'guess' that tones 85 db above .0002 dynes/cm^2 may cause some deafness, either temporary or permanent applies only for long periods of exposure, applied intermittently over months or years. On the other hand, for brief exposures lasting up to an hour, the intensities necessary to cause deafness appear to be in the order of 100 db re .0002 dynes/cm^2 for any frequency or critical band."

The key words in this statement are "for any frequency or critical band." In spite of the fact that Kryter carefully limited his figure to "critical bands" he is quoted as an authority for an 85 db over-all figure as a safe level. This kind of error is being made all too frequently today. It can be avoided by refraining from any reference to a criterion in terms of over-all (20-10,000 cps) values. Actually, Kryter's figure of 85 db *per frequency or critical band* becomes nearer 95 db per band when calculated to octave bands above 300 cps. Below 300 cps this value becomes even higher. Kryter "guesses" in his monograph that "It is possible, but undemonstrable with

present data, that the degree of deafness could be predicted by the use of critical band measures of noise intensity and plotting such measures relative to 85 db above the threshold for pure tones . . ." thus he was actually recommending the use of a curve which would define the permissible noise levels in bands.

Following Kryter's suggestion Beranek subsequently proposed what has been called tentative damage risk criteria for noise, expressed in octave bands. These curves were very similar to those suggested by Kryter, but vary slightly in the high and low frequency ends of the spectrum.

At the University of Michigan Symposium in 1952, Sterner[7] discussed the status of noise standards at that time. He included an analysis of a questionnaire which had been sent to 275 (answered by 222) acoustical engineers, physicists, psychologists, otolaryngologists, industrial physicians and industrial hygienists. There was no general agreement on any phase. In fact, there was evidence of chaos in the wide variety of the numbers proposed by the various recipients. The substantial majority seemed to feel that information available at that time (1952) was not adequate to establish standards for industrial hygiene codes.

The next step in the development of criteria was the appointment in 1952 of an exploratory sub-committee (X.2) of the American Standards Association Sectional Committee on Acoustics, Vibration and Mechanical Shock (Z24).

Their report entitled "The Relations of Hearing Loss to Noise Exposure"[6] is simply an evaluation of the results of investigation of available information which can be used to establish the relation between hearing loss and noise exposure. It does not even suggest a definite criterion. On the title page is the statement, "This report summarizes the fact-finding mission which was taken by the sub-committee; it suggests no standards and proposes no criteria."

The committee employed the services of a technical counsel who visited many industries and collected data from nine plants including about 7,000 audiograms with octave band analyses of the noises to which the subjects were exposed. Much of the report is devoted to a statistical analysis of these data to determine whether or not any relationship between the noise exposure and resultant audiograms existed. The vast majority of the data used represented continuous exposure to steady noise. There was some information from airplane pilots related to intermittent exposures to steady noise and there was a small amount of information on non-steady noises including proof firing and drop forge operations.

For the continuous exposure to steady noise a series of curves was developed providing a means of estimating the effects on hearing at 1000, 2000 and 4000 cycles per second. These so-called "trend curves" were tested against a group of people who had been exposed to six different kinds of noises. It was found that these curves could be used to give a satisfactory estimate of the average hearing loss to be expected at any given test frequency after any specified number of years of exposure to a particular kind of noise. This is purely a statistical approach. Because of a paucity of data, this type of information was not developed for the other kinds of noises. In their conclusion the committee states,

"Standards and criteria for tolerable noise exposure cannot be formulated until decisions are reached on at least the following questions: (1) What kind and amount of hearing loss constitutes a sufficient handicap to be considered undesirable? What role should presbycusis play in the setting of such a figure? (2) What percentage of the people exposed to industrial noise should a standard be designed to protect? In view of the large individual differences in susceptibility to noise exposure, should a noise standard be aimed at preventing hearing losses in 50%, 90%, or even 99% of the population? (3) How should noises be specified and exposures measured? Since different noises are apparently not equally effective in producing hearing losses, agreement must be reached on a standard specification of the spectral and temporal characteristics of the noise.

"It should not be impossible to arrive at partial answers to these questions in the reasonably near future. Meanwhile these issues will be clarified by frank discussion among the groups concerned with the problems raised by exposure to noise."

For *very short exposures* which are in-

termittent, levels above those suggested for continuous exposure can probably be tolerated. Evidence as to what these levels might be is sparse. Rosenblith and Stevens[5] have recommended that even for short exposures, levels of 145 db to 150 db should not be exceeded. Not only is there a possibility of damage to hearing, but these levels may also cause non-otological effects such as blurred vision, disturbance of equilibrium and similar effects.[9]

For *impact noises* which are characterized by sharp peaks, there is some indication that no more damage will be produced than might be caused by a continuous noise having the same *average* sound intensity level.[5] In general, these impact noises are characterized by large peaks of energy which last only a few milliseconds. Between the peaks, the exposure will be that of ambient levels. The period between peaks may vary widely from the order of magnitude of seconds to many minutes. The *average* noise level will thus be substantially lower than the peak level.

We have been handicapped by both a paucity of information relative to the biological effects of such noise patterns and the difficulties in measuring impact noise of short duration. In the case of instrumentation, some progress is being made and manufacturers are beginning to supply "impact meters."

When we can evaluate the noise both as to peak and average sound levels, we will be in a position to collect meaningful data related to the effects of such noises.

In the meantime, there have been some guesses made as to possible criteria for impact noise, based largely on experimental work and some data from gunnery officers. Rosenblith and Stevens have pointed out that data on short-time auditory fatigue indicate that each peak resulting from an impact produces substantial temporary loss followed by recovery within a few seconds. If the impacts occur rapidly enough, there may not be complete recovery from the temporary loss between peaks. Thus following several hours of this type of exposure, there will be a residual loss which may persist for hours or days.

An additional factor which must be considered is the ambient noise levels between peaks. If the background noise between impacts is in a damaging range, the amount of recovery will be reduced or even eliminated. The severity of the problem will be increased if the peaks exceed 150 or 160 db, for there is some evidence that such levels may produce damage regardless of the length of exposure.

The temporary criterion for an impact noise suggested by Rosenblith and Stevens is based on acceptance of their steady state criterion, 95 db *in each octave band between 300 and 10,000 cycles per* second. By calculating the *average* sound intensity for each octave band from the peak values for a drop hammer and modifying the figure (downward) from experimental data they arrived at a tentative criterion for peak values in impact noises, such as drop hammers, about 10 db per octave above the criterion for steady state noise. This is specifically for "the protection of operators in a drop forge shop from the noise of their drop hammers."[6] It cannot necessarily be applied to impact noises having peaks of different duration or having substantially different intervals between peaks.

Conclusion

THERE ARE at the present time several organizations actively collecting data in an attempt to provide some sort of damage risk criterion which can be validated. Perhaps the most active of these is the Sub-Committee on Noise in Industry of the American Academy of Opthalmology and Otolaryngology. In addition, the Armed Forces - National Research Council Committee on Hearing and Bio-Acoustics (CHABA) is establishing a tentative standard for the use of the Armed Forces. A considerable amount of progress has been made and some information will probably be forthcoming in the relatively near future. In the meantime, such standards as Kryter, Beranek, and Rosenblith and Stevens have suggested will prove useful as guides, particularly in determining the necessity for either engineering control or hearing conservation programs. It should be understood, however, that they are only tentative and subject to modification.

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Air Pollution Course

AN INTENSIVE, two-week course on "Air Pollution" designed for physicians, industrial hygienists, and engineers concerned with the problem of community air pollution, will be given by the New York University Post-Graduate Medical School from November 26 through December 7, 1956.

The course will review the basic toxicology of the principal air pollutants, micrometeorological factors, the effects of air pollution on agriculture and commerce, and methods for sampling and analyzing the various toxic components. Also described will be the sources of air pollution and methods of control. Tuition for the course, which is to be given in cooperation with the New York University College of Engineering, is $75. For further information, write the Dean, NYU Post-Graduate Medical School, 550 First Avenue, New York 16, N. Y.

Flow Calibration OF HIGH-VOLUME SAMPLERS

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University of California, Berkeley

WITH INCREASING use of high-volume samplers for assay of particulates in large volumes of air, a need is felt for determining the air flow rate through the filter. This was called to our attention by the sampling network for air pollutants of the Public Health Service in which program some hundred or more filtration samplers are in use.[1] A requisite of such sampling devices is that they handle 40 to 70 or more cubic feet of air per minute, a quantity not readily measured by flowmeters or gas meters available in most laboratories.

The type of high-volume sampler under consideration is shown in Fig. 1. This equipment has a built-in flow rate meter which measures a small aliquot of the total volume. Its scale is arbitrary and is probably reasonably accurate. In several possible ways, however, the flowmeter can become maladjusted, so that its occasional calibration is in order.

Several techniques come to mind for making such a calibration. These include velocity traverses at the filter face with a thermoanemometer,[2] dilution calibration,[3] and velocity or volume measurements in a duct used as a miniature wind tunnel. After preliminary experimentation with velocity traverses and with dilution of CCl_4 in a 350 cubic foot chamber, the choice of technique fell to a very simple procedure utilizing a venturi meter in small duct-work upstream of the filter. This system is illustrated in Fig. 2.

The venturi meter is one designed after that illustrated in *Industrial Health Engineering*,[4] with a two-inch i.d. throat and four-inch duct. The pressure taps were connected to a one to eight inclined manometer to magnify the readings. Six feet of four-inch pipe were added upstream of the venturi with a honeycomb straightener to minimize turbulence at the venturi.

An adapter was constructed to connect the filter holder of the sampler to this flow system. Care was taken to insure the integrity of the flow system at this point, since any inward leakage at this juncture would not be measured at the venturi. In order to simplify the variation of air volume through

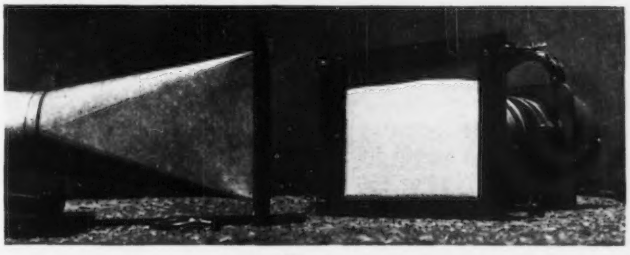

Fig. 1.
High-volume sampler, filter medium and adapter to venturi meter.

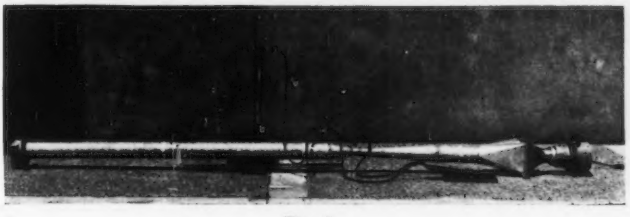

Fig. 2.
Flow calibration system.

The present address of Mr. Keagy is Community Air Pollution Program, Public Health Service, Sanitary Engineering Center, Cincinnati, Ohio.

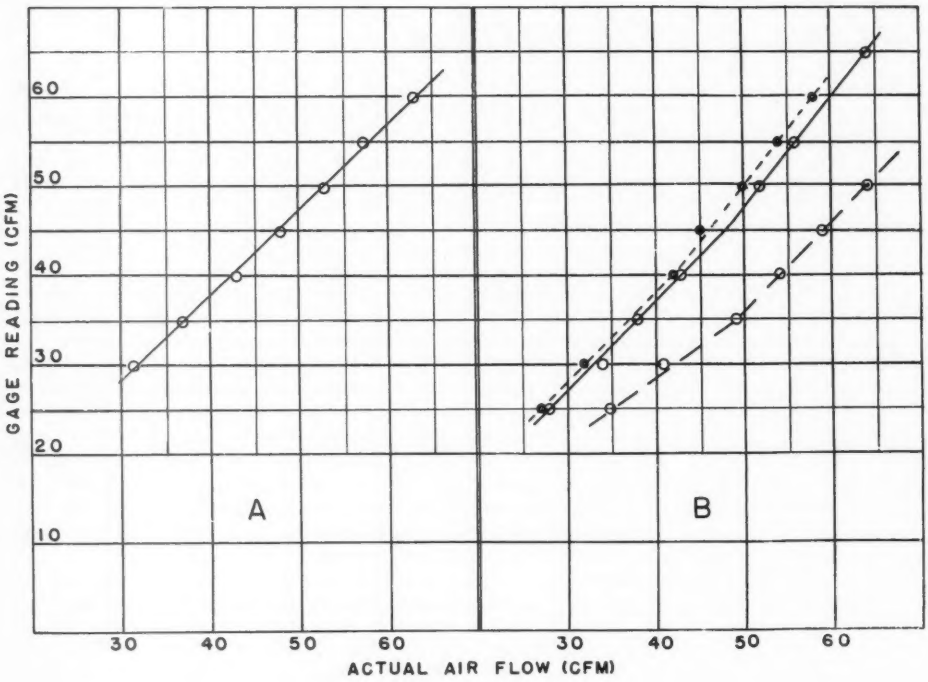

Fig. 3.
Calibration curves for high-volume samplers. A. Network sampler. B. Sampler as received (solid); maladjusted (dashed); readjusted (dotted).

the filter, a variable voltage transformer was used to control the fan speed through a range such that air flow measured on the gage of the high volume sampler could extend through its useful range. Without this arrangement it would be necessary to add more filter medium or otherwise obstruct flow at the filter holder in order to vary the volumetric rate.

To increase the precision of the measurements, the venturi meter was calibrated against an industrial gas meter (positive displacement type) located at the meter shop of Pacific Gas and Electric Company. This is mentioned to call attention to this type of resource for basic large volume rate measurements. The meter, which is bulky and heavy, would be suitable for calibrating high volume samplers but is not ordinarily among the instrumentation of air pollution or industrial hygiene laboratories. Once calibrated, however, the small venturi meter is readily stored, moved or set up for use.

Results

WITH THE CALIBRATING equipment assembled, a group of 12 high-volume samplers was calibrated with rechecks on many points of the curves. To indicate the simplicity of the procedure, ten of these instruments, having identical filter holders, were calibrated in a time trial. Ten minutes was an adequate amount of time to hook up and complete a calibration of the useful flow range of each of them.

Fig. 3A shows the calibration curve for a high-volume sampler as received for use in the air pollution network of the Public Health Service. The solid line of Fig. 3B shows the calibration for a second sampler as received from the factory. The dashed curve is that of the same equipment, with a small but significant maladjustment of the flow gage intentionally made. A similarly significant maladjustment could occur accidentally in handling the instrument. The third curve of Fig. 3B (dotted) is for the

TABLE I.
GAGE FLOW AND MEASURED FLOW FOR HIGH-VOLUME SAMPLER

	As Received			Maladjusted			Readjusted		
Gage	Venturi	Diff.	% Diff.	Venturi	Diff.	% Diff.	Venturi	Diff.	% Diff.
65	64	1	2						
60							58	2	3
55	56	1	2				54	1	2
50	52	2	4	64	14	28	50	0	0
45				59	14	31	45	0	0
40	43	3	7	54	14	35	42	2	5
35	38	3	9	49	14	40			
30	34	4	13	41	11	37	32	2	7
25	28	3	12	35	10	40	27	2	8

All volume rate measurements in cubic feet per minute.

same instrument, but with the flowmeter readjusted to give zero correction at a volume rate of 50 cubic feet per minute. The data for Fig. 3B are shown in Table I.

Conclusions

THESE RESULTS indicate that the gage incorporated into the commercial high-volume samplers studied is capable of measuring flow rates within 10% of the actual rate over a range from about 25 to 70 cubic feet per minute. In our experience, the instrument as purchased is not necessarily within that limit of accuracy but by readjustment can be brought within it. Over a narrower, preselected range, the gage readings may be adjusted to be within 5% of actual flow without change of scale.

Clearly the calibration range of this technique could be increased to encompass larger flow rates by modification of venturi, duct-work and/or manometer slope and fluid. To lower the calibration range would require increasing precision of pressure differential measurement and could probably be accomplished at some cost in convenience and simplicity. It is worth noting that the venturi calibration should be made preferably at the conditions of temperature and pressure to be used. Corrections could be made for variations from these conditions by taking account of the density of air in the standard venturi formula.

It is comforting, in this as in other environmental assay procedures, to be able to check quickly the flow calibration. The procedure described accomplished that goal.

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Recent Industrial Hygiene Developments

—A SYMPOSIUM—

THE FOLLOWING papers were presented at the Joint Session of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION and the American Conference of Governmental Industrial Hygienists, at the 1956 Industrial Health Conference in Philadelphia, April 24, 1956.

In the Field of Air Pollution

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PROBABLY the most significant development in the past year in air pollution as it may affect industrial hygiene or any of the health-related sciences is the passage of Public Law 159. Public Law 159, which was signed by the President on July 14, 1955, authorized a comprehensive program of community air pollution research and technical assistance to the States, communities, and other organizations. The act declares "the policy of Congress to preserve and protect the primary responsibilities and rights of States and local governments in controlling air pollution, to support and aid technical research, to devise and develop methods of abating such pollution, and to provide Federal technical services and financial aid to State and local government air pollution control agencies and other public or private agencies and institutions in the formulation and execution of their air pollution abatement research programs." The law authorizes the expenditure of funds not to exceed $5 million per year for a period of five years. In 1956, $1,722,000 was appropriated. For fiscal year 1957, $3,000,000 has been requested.

The community air pollution program within the Public Health Service is carried out by the Divisions of Sanitary Engineering Services and Special Health Services. The technical work of the Division of Sanitary Engineering Services consists of technical assistance, training, and demonstrations related to engineering and is carried out at the Robert A. Taft Sanitary Engineering Center. The Division of Special Health Services has the responsibility for the determination of the health effects of air pollution. The technical studies, particularly as they relate to toxicology and medical effects, are being performed at the Occupational Health Field Headquarters. The primary objective of the toxicologic studies is determination of the toxic effects of such air pollutants as ozone, nitrogen oxide, and sulfur derivative hydrocarbons on test animals. Much of the medical research is being carried out through contractual arrangements with universities and private organizations. These relate primarily to studies of the biologic effects of air pollution on health. Included are studies of the feasibility of using tissue culture and tissue enzymes to evaluate the toxicity of different air pollutants. A third project at the National Institutes of Health involves the statistical determination of geographic variations in the leading causes of death. This information, when correlated with environmental findings, will provide leads for community epidemiologic studies of air pollution.

Because of the diverse interest of many federal agencies in air pollution, an interdepartmental committee on community air pollution has been organized. The Departments of Agriculture; Commerce; Defense; Health, Education, and Welfare; and Interior; and the Atomic Energy Commission and National Science Foundation are represented on the committee. This committee will provide liaison between and coordination of federal activities relating to air pollution. It will review from time to time the policies and programs related to community air pollution of the federal agencies, the general status of technical knowledge concerning air pollution, particularly with regard to the area and scope of needed research and other technical activities and advise the Surgeon General thereon. At the

first formal meeting of the committee, held in November, 1955, the areas of interest and responsibility of each of the participating agencies were determined. Public Law 159 vests the primary authority for air pollution studies in the Public Health Service but authorizes it to cooperate with and finance studies of other federal departments.

In addition to research—both through direct operation and contracts—another important activity has been technical consultation to the States and communities. Personnel were assigned to the California State Department of Public Health to aid in a special study of the Los Angeles problem and to assist in the development of a statewide program. Other personnel have been assigned by the Sanitary Engineering Center to the Los Angeles Air Pollution Control District to assist in the conduct of a specialized aerometric survey and oil refinery studies. Another cooperative effort involving special studies of air pollution in the Louisville, Kentucky area has been initiated to study the source and character of air pollutants in that area. This study, which is expected to be completed in two years, was initiated in January, 1956.

Direct research operations at the Sanitary Engineering Center included extension of the national air sampling network to a total of 45 cities and 74 sampling stations. Analysis of the material being collected includes determination of the weight of material collected, identification of 17 metals, certain anions and organic fractions as well as the radioactivity levels. Twenty-six research projects are under way at the Sanitary Engineering Center. These include research to establish the relationship between atmospheric pollution and meteorologic variables, studies of the performance and design factors involved in controlling air pollution from incinerators, and development of control devices utilizing fabric filters. Eight studies are under way to develop methods for determining the composition of air pollutants and for the development of instruments for air pollution measurement. Work also includes a detailed examination of certain air samples, studies of economic costs of air pollution, and studies of control in several industries.

In addition to its directly conducted research activities, the Public Health Service is supporting air pollution studies in other federal agencies. The U. S. Weather Bureau, U. S. Bureau of Mines, and National Bureau of Standards are all undertaking important studies. The Weather Bureau, for instance, is studying the meteorologic parameters contributing to the severity of air pollution. The Bureau of Mines is investigating the incineration of combustible wastes, evaluating sulfur dioxide removal processes, and studying the effluents from automobile exhausts. The Bureau of Standards is developing methods for sampling and analysis of air pollutants and is studying the interreactions of air pollutants at the source and in the atmosphere. Negotiations have also been completed with the Library of Congress to provide a continuous abstracting service and to compile an annotated bibliography covering all phases of the air pollution literature.

Utilizing the grants mechanism of the National Institutes of Health, to date, 20 air pollution research grants, totaling $481,359 have been awarded. Of these, six are in the field of physical science and engineering and the remaining 14 are concerned with the health effects of air pollutants.

Training will be eventually another major activity under Public Law 159. To date, the Sanitary Engineering Center has held several seminars for State and local personnel. The fact that 95 people from 31 States, 14 cities, and five countries attended the September, 1955 seminar indicates the widespread interest in air pollution. Another technical seminar was held in 1956 which concerned itself with atmospheric sampling, analytic procedures, sampling theory and techniques, and air pollution meteorology. A third seminar is planned for May, 1956.

These developments, all related to the passage of federal legislation in the air pollution field, will probably stimulate expanded research activities in air pollution, not only by federal agencies but by private organizations as well. In passing this legislation Congress recognized that the Federal Government had a responsibility in research and development but it left the control of air pollution in the hands of local authorities and private enterprise. The research being stimulated by this law promises to have the same beneficial effect in the air

pollution area that stream pollution investigations had in the correction of interstate waste problems.

In the Field of Chemistry

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THE PAST YEAR has produced a number of papers relating to the chemistry of industrial hygiene which serve to indicate that the field is an active one, and one in which a tremendous amount of work remains yet to be done. A complete review of all published work would be prohibitively long; instead, the present effort seeks to present some of the more pertinent accomplishments noted in the past year's literature.

Classic problems associated with such well-studied substances as lead and silica continue to be studied, as well as entirely new problems related to materials only recently used by industry. Jephcott and Wall,[4] for example, reviewed existing methods for determining free silica by means of phosphoric acid, and concluded that several modifications of such methods improved the accuracy of the determination. Particular attention was paid to the errors which arise when the size of particles being analyzed was neglected, and data are presented to substantiate their conclusions.

A new dithizone procedure for determining lead in urine was described by McCord and Zemp,[7] in which lead, as the iodide, is extracted from methyl isopropyl ketone, then removed with sodium hydroxide prior to its estimation as the dithizonate.

In the continuing attempt to fully utilize the speed and ease of spectrographic methods, Kumler and Schreiber[6] have published a method for lead in blood which is shown to be more rapid than chemical methods for large numbers of samples, and which is as accurate and sensitive as needed for this determination. Whole blood samples are partially wetashed, bismuth is added as an internal standard, and a small portion of the resulting homogenous liquid is then introduced in carefully controlled fashion to the electrode.

The spectrograph was also used by Keenan and Kopp[5] to determine trace quantities of cobalt in animal tissues. For many purposes, direct analysis of tissues is possible by their method, and when extreme sensitivity is required, the samples may be chemically treated in such fashion that the cobalt is greatly concentrated.

Mercury was the subject of two papers published by different groups, both choosing to use dithizone as the color-forming reagent. Polley and Miller[9] devised a microprocedure suitable for either biological or mineral materials, and Campbell and Head[1] produced a single-extraction method for urinary mercury which utilizes the chelating agent Versene to complex interfering metals. The various ashing procedures used to destroy the organic matter of urine were studied, and the sulphuric acid—permanganate ashing—was considered superior to the others.

An unpublished work of Shepherd[13] at the National Bureau of Standards appeared posthumously, and dealt with the N.B.S. indicating gels for carbon monoxide. Using the procedures outlined by the authors, the sensitivity of the gels may be greatly increased, so much so that as little as 0.1 PPM CO may be determined. The obvious use of this great sensitivity is the analysis of air in conjunction with air pollution studies, a field in which existing methods of carbon monoxide estimation have been largely inadequate.

Smith and Gardner[15] studied the determination of fluoride in urine and recommended a method similar to that generally in use. Samples are heated with calcium oxide, distilled and colorimetrically evaluated with Alizarin Red S and thorium.

A needed specific method for acrolein in the presence of other aldehydes was devised by Van Sandt, *et al.*[16] Analysis is performed polarographically after samples have been collected on silica gel. Care must be exercised throughout the analysis to exclude air from the prepared sample.

Hydrazine in both air and blood plasma was investigated by McKennis and Witkin,[9] and Prescott, *et al*,[11] respectively. In the air determination, which is also suitable for

ammonia vapors, samples are collected in sulphuric acid, ammonia is removed by aeration after suitable treatment, then nesslerized, and hydrazine is reacted with p-dimethylaminobenzaldehyde. For the plasma estimation, 4-pyridylpyridinium dichloride is used to develop a color with as little as 0.1 microgram of free hydrazine.

A rapid method of detecting aniline vapors in air was reported by Riehl and Hoger,[12] in which paper strips impregnated with furfuralacetic acid mixture turn pink to red when exposed to aniline vapors.

Hill and Johnston[2] and Hill, *et al*,[3] published further studies relating to boron, describing both a rapid iodometric method for boron-containing atmospheres, and a direct ultra-violet procedure for decaborane which does not require conversion to boric acid.

A rapid technique for evaluating industrial benzidine exposure was described by Sciarini and Mahew,[13] in which a simple urine test is performed. The specimen is rendered alkaline, an extraction with ethyl acetate-acetone is performed, and the yellow color developed with Chloramine T is measured spectrophotometrically.

Kusnetz[7] devised a rapid field method for measuring the concentration of radon daughters in mine atmospheres. After collection of samples on filter paper, the alpha activity is measured, and results are converted directly to fractions of tolerance level by graphical means.

Certainly, the great diversity of chemical problems in industrial hygiene is well exemplified by the subjects treated in this brief review, and constant effort is necessary to improve existing methods and devise new, more rapid, and more specific methods.

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In the Field of Engineering

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IT IS DIFFICULT to cover the field of industrial hygiene engineering developments in recent years without the possibility of conflicts with developments in related fields such as air pollution control. In the limited time provided, however, I am restricting my discussion to items which may be considered logically as problems of the industrial hygiene engineer.

Industrial hygiene engineering developments are not apt to be startling in considering a short period since they are usually based on long time process evaluations and critical studies of new manufacturing operations or methods of production.

It is true that, in general, industrial hygiene engineering developments must keep pace with engineering developments in order to anticipate, prevent, or minimize hazards. In many instances the anticipation approach is neglected or greatly delayed. The process is often placed in operation without prior discussion or consideration by individuals who could recognize potential contamination of the working environment or spot an unusual hazard from radiation, inhalation or skin effects.

Welding Studies

THE DEVELOPMENT of new welding techniques such as the inert gas shielded arc is a recent example of a problem where conventional control methods did not apply because the conditions of contamination are unique. In welding aluminum with argon or helium as the shield gas it is possible to

control the fume at the source and yet not eliminate exposure to ozone completely. This is because the ozone is created by ultraviolet radiation from the aluminum spectrum. We have studied this in detail[1] and so have others such as Ferry.[2] However, when the process involves the use of the inert-shielded arc on mild or stainless steels the radiant energy produced does not create as much ozone so conventional methods appear to give nearly complete control. From our experience, the only reasonable approach to the high ozone levels created close to the breathing zone is to provide an air supplied helmet to the worker or supply sufficient general ventilation to dilute the concentration below permissible values. General ventilation may be only partially satisfactory, is likely to be an economic burden and will cause a drafty condition. It therefore appears to be less desirable.

The recent use of carbon dioxide as an inert shield gas for mild steel welding is increasing and studies of engineering control for its use are lacking. The question of carbonyl formation is unanswered, however, theoretical and practical considerations of the temperatures and radiation involved make the probability it can be present appear unlikely. The use of conventional local exhaust ventilation, if maintained at a distance which does not disturb the inert shield gas flow, has not created any problems in practice for CO_2 welding gas operations.

Gas Cleaning

WORK on the development of fibrous media and filters in recent years has proceeded at a fairly rapid pace. The application of these developments to control contamination in working environments is becoming increasingly important. Studies such as those reported by Fitzgerald and Detwiler[3]; Kramer[4]; Silverman, Conners, and Anderson[5] have indicated that new techniques may be applied to aerosol filtration so that efficiencies beyond 99.99% (penetrations of less than 0.01%) can be obtained on aerosols of submicron particles. Of particular interest in this area is the further delineation of forces in filtration mechanisms. The work cited above has contributed to our knowledge of electrostatic forces present in fibrous filters.

In the field of electrostatic precipitation the recent work by Thompson, Myron and Davis[6] has indicated important factors to consider in operating on open hearth steel furnaces. These authors have shown that, using pipe type units, it is possible to clean open hearth fume to 98 to 99% with retention times of 0.58 to 0.88 seconds; to 96 to 98% with periods of 0.44 to 0.58; and to 92 to 96% with 0.35 to 0.44 periods. Water injection was not of material assistance in improving efficiency. Dry plate precipitators showed less effective results since efficiencies obtained ranged from 83 to 97%.

A new approach to high temperature gas cleaning has been developed in our laboratory and is presented in three recent papers.[7,8,9] This method involves the use of refractory slag wool fibers made from by-product blast furnace slag. These fibers are formed into a slurry which is dried in a continuous filter, passed through the contaminated gas stream and returned to the slurry for washing and reuse. Laboratory studies and early pilot plant investigations appear promising. Efficiencies above 90% have been obtained in both cases on 0.03 μ fume at resistances of two to six inches of water.

The important factor is that the filtration velocities used for this performance have exceeded 100 feet per minute which considerably reduces the size of equipment necessary for large gas volumes. Typical 300 ton open hearth furnaces involve 40 to 50,000 cubic feet of gas at temperatures above 1000°F.

A recent description of the application of precipitators to ferro-manganese blast furnace cleaning has been given by Good.[10] Many technical difficulties were encountered and overcome before the present satisfactory engineering control of pollution was obtained. Other precipitator studies on fly ash collection have been reported by Flodin and Haaland[11] and White.[12]

The mechanism of separation on louver-type dust separators has been studied at length by Smith and Goglia.[13] Their data showed that the percent of initial dust separated was essentially independent of initial air velocities and dust concentrations. Particles as small as 10 μ were separated although the device is more effective on particles above 40 μ.

Engineering Control of Working Environments

NEW STUDIES in this area are limited. A recent study by Venable[14] is of interest in that it shows many aspects of handling engineering improvement of an aromatic solvent exposure. Venable reports on methods of reducing or controlling losses at the source.

Control of general exposures to uranium by limiting the degree of contamination of steel scrap is discussed at length by McAlduff.[15] This article focuses attention on the need for evaluation of the many aspects of the atomic energy industry which are beginning to pervade other industries. A recent article by Kramer and Goldwater[16] describes the control of mercury hazards during its use as a casting material. The fact that the air concentrations could be maintained within safe values when using large amounts of mercury even though at low temperature in most exposures is a tribute to engineering ventilation design.

At last year's (1955) engineering session of the AIHA we presented the results of a study of resistance losses in various types of flexible hose.[17] These data permit more accurate selection of hose, blowers and exhausters and other air moving equipment. The effect of spiraling flow and its influence on resistance was observed. This caused the friction factor to increase with increasing diameter.

New Books

IN THE PAST YEAR new books have appeared which will be of appreciable value to industrial hygiene engineers. One is the recent revision of Drinker and Hatch.[18] The new edition is thorough and includes the latest approaches in industrial hygiene engineering.

Hemeon's recent book[19] on plant and process ventilation is an excellent coverage of the field and presents some novel treatment of certain problems. Also appearing in the past year in book form are the proceedings of the first international congress on air pollution.[20] A number of technical papers on engineering control of air pollution are included in this volume.

Another recent book of interest to industrial hygiene engineers is a new handbook on electroplating engineering.[21] Two chapters in this book cover industrial hygiene engineering approaches and a number of other related chapters are of interest.

Some of the papers included in the recent proceedings of the International Conference on the Peaceful Uses of Atomic Energy, which just appeared (April, 1956) cover many aspects of industrial hygiene engineering as applied to atomic energy problems. Those wishing to become acquainted with recent developments in this field of activity should consult the pertinent volumes.

General

IN MAKING this review I was impressed with how little really recent work could be strictly claimed as solely industrial hygiene engineering accomplishments. Perhaps this is because many aspects of industrial hygiene engineering can be performed by people with specific basic training such as mechanical, ventilation or chemical engineers. It may also be attributed, at least partially, to modesty of industrial hygiene engineers. Problems once solved are viewed as a finished project and they are too concerned in solving new ones than in reporting success on old items. More reporting of successful engineering control of exposures and the features which are uniquely those of industrial hygiene should be encouraged.

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In the Field of Noise

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NOISE CONTROL is demanding an increasing portion of the Industrial Hygienist's time and, therefore, justifies an overall look at recent developments.

Management Acceptance

ONE OF THE most significant developments in the past year has been the acceptance by management of the facts that (1) they have a noise problem, (2) it is serious enough to warrant action, and (3) the responsibility of protecting employee health and safety from excessive noise belongs to management. In most cases we no longer need to spend valuable time convincing management, but are at liberty, in fact, encouraged, to pursue methods of controlling noise.

AIHA Noise Manual

THE AIHA recognizes the need for a practical manual to guide Industrial Hygienists in controlling industrial noise. To fill this need they have formed a noise committee and charged it with the responsibility of preparing such a manual. Subjects covered by this manual will probably be:

(1) Physics of sound.
(2) Measurement of sound.
(3) Man's physiological reaction to sound.
(4) Hearing conservation.
(5) Engineering control of sound.

Second drafts of each chapter of this manual have already been completed and it is expected that the final draft will be completed for the 1957 annual meeting. It is not too late to include suggestions or data to help make this manual of maximum usefulness. K. M. Morse, of the U. S. Steel Corporation, chairman of this committee or any committee member as listed in the current issue of the *Quarterly*, will be glad to accept any contribution. Of particular interest would be examples of noise control treatments tried and found successful. No one of us has had experience with all types of noise problems but by pooling our accomplishments all should benefit.

More Information Now Available

ORGANIZATIONS outside our own AIHA have been active during the past year in making available recent technical and practical information on noise control. Many organizations are involved but time permits the mention of only a few.

ASSOCIATED INDUSTRIES OF NEW YORK STATE, in their annual meetings on noise control, present papers on practical solutions to noise problems. These papers are presented by representatives of various companies and are published in the *AIHA Quarterly*. Each year these meetings increase in value as the activity in noise control increases.

THE NATIONAL NOISE ABATEMENT SYMPOSIUM held yearly at the Illinois Institute of Technology presents a similar program except of a more technical nature. The proceedings of these meetings are published in *Noise Control*.

THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY sponsors a conference on noise control about every two years and the one this past year was exceptionally good in that an attempt was made to provide the Industrial Hygienist with practical data for field application. Proceedings of this conference were also published in *Noise Control*.

Since the magazine *Noise Control* has been already mentioned twice, it might be in order to say that this quarterly publication has established itself during the past year as a valuable reference for Industrial Hygienists who are concerned with controlling industrial noise. It provides technical and practical data on all phases of the problem.

Machinery Noise Specifications

IN OUR HASTE to get existing noise problems under control we must not overlook the preventive side of the problem as far as new construction or machinery replacement is concerned. Manufacturers are awakening to the fact that noise production characteristics of a machine are important specifications. Some are taking steps to provide such data. It is quite generally accepted that noise power output is the best specification for predicting the noise production characteristics of machines, for specific conditions of installation. Most acoustical engineers agree that the echo-free room, i.e., anechoic chamber, provides the best environment for making measurements of sound power output. However, few manufacturers feel they can afford such facilities. As a result, organizations such as the American Institute of Electrical Engineers (AIEE), National Electrical Manufacturers Association (NEMA), American Fan Manufacturers Association (AFMA), Industrial Unit Heater Association (IUHA) and the American Society of Heating and Air Conditioning Engineers (ASHAE) are investigating less costly means of measuring sound power output. There is indication that this might be accomplished in the next year or two. In the meantime, some companies are using some adaptation of the American Standards Association (ASA) Apparatus Noise Measurement Standard together with some noise criteria to identify excessively noisy equipment. By bringing this to his attention, the manufacturer is rapidly being made to realize that noise is a competitive problem. It is interesting to note how readily other manufacturers can get in line as soon as one solves the noise problem. The manufacturer of electric motors provides a good example. As soon as one manufacturer proved that quiet motors were practical, others found they could also meet the demand. As a result, you can now select a motor that will not create a noise problem.

Our job is to warn our companies against buying new noise problems. The first step in preventing this is to supply Design and Purchasing Departments with noise specifications for machinery.

Automatic Audiometer

TO ASSIST in hearing conservation programs where large numbers of hearing tests must be made, a new audiometer has been developed called the automatic audiometer. With this device the patient takes his own audiogram after having been given a few simple instructions. One operator can supply the instruction necessary to keep three automatic audiometers in operation. Indications are that to justify automatic audiometry, enough tests to keep three machines in operation are required.

Impact Meter

EVEN THOUGH less is known about the relation between hearing damage and exposure to impact noise than for steady state noise, fairly accurate field measurements of impact noise is desirable if we expect to develop damage risk criteria or evaluate corrective measures. Until recently, field measurements of impact noise was too complicated to attract widespread use. The General Radio Corp. now has available an instrument called the Impact Noise Analyzer which gives promise of improving this condition. This instrument is simple to operate, easily portable, relatively inexpensive, can be used with frequency analyzers and provides fairly accurate measurements of impact noise. It is hoped this instrument will be valuable in the study and control of impact noise which has been sadly neglected up to now.

To summarize these recent developments:

1. Management is accepting the noise problem and is looking to us for the answers. It is our move now to get the job done.

2. AIHA will soon have available a manual on noise control which should be a guide in solving industrial noise problems. This should considerably reduce the necessity of searching through many sources for the answers to your problems.

3. Organizations outside the AIHA are

also active in this field. While it is practically impossible to cover them all, it is wise to keep an eye on a few to provide as broad a coverage as possible.

4. Don't buy new noise problems. Promote the use of machinery noise specifications to emphasize the importance of the noise problem.

5. If you have many audiograms to take, consider the automatic audiometer; it might save you money and provide more uniform data.

6. If you have impact noise problems, you should consider the use of an Impact Noise Analyzer.

Only a few of the recent and important developments in the field of industrial noise control (as far as the Industrial Hygienist is concerned) have been discussed. The interest shown in this field today indicates that new and significant developments will be forthcoming in increasing numbers. If one is to keep abreast of this new and rapidly developing field, constant vigilance of current literature will be required.

In the Field of Radiation

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IT IS NOT possible to cover all the developments in the field of radiation in the course of this paper, but after discussing the subject with several persons in this field, I have concluded that the following are probably the most significant.

Many developments have been primarily "administrative," that is, they deal with the development of regulations, codes and standards and the matter of agency jurisdiction over health and safety.

In June, 1955, a conference was held on the subject of health physics, and as a result of that conference, a preliminary organization of professional health physicists was formed.

In July, 1955, the AEC published its proposed standards for protection against radiation as part of Article 10 of the Code of Federal Regulation. Although other parts of the same Title may also be based upon a need to consider the hazardous aspects of atomic energy, Part 20 will be among the first Federal occupational health codes to be enforced by a Federal agency. Many interesting new concepts in radiation protection are included in the AEC's proposed code. It is expected that a revised draft will be forthcoming shortly.

Many papers on radiation protection were submitted to the International Conference on the Peaceful Uses of Atomic Energy, which was held in Geneva in August, 1955. The legal and administrative aspects of the problem received a great deal of interest.

In December, 1955, the American Standards Association called a National Conference on Standardization in the Field of Nuclear Energy to review its program in this area and to obtain the thinking of a large cross-section of industry, government, labor and others on the need for additional American Standards Association activities.

As a result of this meeting, a Planning Committee was established to review the present status of standards and recommend appropriate action. This Committee met in full session on February 15, 1956, and this meeting was followed by meetings of the various subcommittees. Reports of these subcommittees were analyzed on March 15, 1956, at a meeting attended by the subcommittee chairmen and the Chairman of the Planning Committee. The major recommendation was for the American Standards Association to establish a nuclear standards board.

In December, 1955, the National Bureau of Standards issued Handbook No. 61 on the regulation of radiation exposure by legislative means, which contained the recommendations of the National Committee on Radiation Protection concerning the development of acts and regulations on the part of state government.

In March, 1956, the New York State Health Department and the New York State Labor Department radiation protection regulations became effective.

This same month, the United Nations Radiation Committee had its first meeting and elected officers. The next meeting will be in about five months. This Committee was established in December, 1955, by the United Nations as a committee of specialists from 15 nations to collect information on radiation levels and radiation effects on man

and his environment from 85 nations. Working groups were set up on genetics, internal and external radiation effects, natural radiation background, exposure during medical procedures and occupational exposure. It is not clear at this moment what the relationship is between this special committee and the World Health Organization which published in July, 1955, a summary of national laws and regulations on radiation protection.

On March 20, the Atomic Industrial Forum conducted a conference workshop on Public Relations for the Atomic Industry. In discussing problems arising from the peacetime uses of atomic energy, Andrew B. Biemiller, representative of the AFL-CIO, stated that "the problem that comes up most of all is that of health and safety. There have been some rather lurid tales out about the potential dangers of the industry."

Early this month the International Commission on Radiological Protection and the International Commission on Radiological Units met in Geneva. As a result of this meeting, some revisions are to be made in airborne concentration limits for radioisotopes and a new edition of the National Bureau of Standards Handbook No. 52 may be prepared.

These activities indicate diversified attempts to evaluate the importance of radiation protection. In some industries and areas the problem is considered negligible and in others it is paramount. The increase in legislative activity points to the need for precise legal definitions of such terms as "radiation hazards," "radiation installations", and "qualified expert." These definitions, however, relate to the philosophy of the agency or the organization toward the importance of radiation protection in its scope of activity.

A problem exists in placing radiation protection into proper perspective. The qualified, responsible officials must face this problem as they attempt to step back and take a hard look at the field of radiation hygiene.

It has been said that the development of control techniques for ionizing radiation is no exception to the development of similar techniques for other hazards in industry. Radiation is reported to be considered as another type of hazard by industrial hygiene. The same authors indicate that for many radiation problems there is no need for a specialist such as a health physicist, since the problem of radiation may be minute compared to other health and safety hazards which may exist in the same installation. It has been said that there is no sound reason for considering ionizing radiation as particularly different when one considers placing the control of radiation into a new, versus an existing, governmental agency.

Arguments on the other side state that all radiation is potentially harmful and that radiation is peculiar in that there is a cumulative effect. Genetic effects are thought about by many workers before they express concern over more immediate possible damage. Few other occupational hazards associate themselves in the minds of workers with genetic damage. Many agree that there is need for people who are moderately acquainted with radiation to recognize the potentialities for harm and call upon a health physicist for assistance. Both the New York State Health Department and New York State Labor Department have been reported to have health physicists on their staffs to act as experts and consultants to their field forces on radiation problems.

The problem of preventing injury to human beings from radiation is not new. Many of you have been studying it for some time, even prior to the development of a sustaining chain reaction. The recent developments above, however, indicate the need for careful technical scrutiny of all concepts concerning the achievement of a "safe" radiation environment before these concepts are placed into laws which subject someone to fine or imprisonment if they are ignored. Skilled radiation hygienists may agree on the few basic laws of nature which have been discovered concerning the effects of a given dose of radiation upon a given individual or group of individuals; there may be some differences as to which laws of nature must be considered in each case.

Translating these natural laws into man-made regulations requires consideration of such factors as personnel requirements for enforcing, budget for salaries and instrumentation, delegation of authority to new or existing agencies, public relations aspects, and inter-departmental liaison.

Conclusion

THERE EXISTS a continuing need to have a coordinated, objective appraisal of radiation hazards to develop a definition satisfactory to health officers in government and industry and to legal authorities. Having defined a "hazard," appropriate controls can be more clearly spelled out on the degree of competency of the supervising personnel.

In the Field of Toxicology

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IN THE BRIEF space allotted to review recent developments in the field of industrial toxicology, those subjects have been selected that appear to be of interest, either because of the unique character of their response or their indications of importance to industrial health. In the vast field from which to choose it is obvious that other selections might have been made equally as well.

New Hazardous Compounds

ACRYLAMIDE, CH_2=CH-$CONH_2$, a chemical intermediate of great potential usefulness for the formation of polymers and copolymers, plasticizers, dispersants and other purposes, has the unusual property of being insidiously neurotoxic at relatively low levels of intake, while at the same time showing unremarkable toxicity from acute doses (oral LD50, 170 mg/kg).[1] Acrylamide is toxicologically remarkable in other ways.

1. It shows practically no species variation; effective doses for the cat, dog, and rat were essentially the same.

2. Its physiologic effects are produced equally readily by any route, oral, skin or eye.

3. A definite quantity of acrylamide will produce the characteristic central nervous system syndrome of disturbed gait, postural tremors, visual and auditory hallucinations and muscular atrophy, irrespective of the dosage schedule used.

4. There is an anamnestic response, in that following cure, lesser amounts of acrylamide recall the syndrome. Fortunately the effects are reversible, although in severe cases recovery may require years (in man). No threshold limit defining the level for safe exposure has yet been set.

Acrylamide represents an interesting demonstration of our current inability to predict the grave physiologic consequences from chemical structure; the closely related amide, propionamide ($CH_3CH_2CONH_2$), is used as an animal feed supplement. Here, again, is another striking case of the addition of a second double bond in the molecule to form a conjugated system with conference of remarkable toxicity. Another well-known example is the 44-fold greater toxicity of crotonaldehyde compared with its saturated analogue butyraldehyde (Skog, Acta Pharm. Tox. 6, 299, 1950). Less well known, but equally striking is the highly lacrimatory power of conjugated unsaturated nitrocompounds such as 1 nitroisobutylene compared with the unsaturated but not conjugated isomer, 1-nitroisobutyl-2-ene which has no marked lacrimatory powers. The potent irritating capacity of the diisocyanates discussed below are other examples of the effects of conjugated unsaturated compounds. Examples could be multiplied almost endlessly.

As a new group of monomeric substances used in foam rubber, lacquers and for other purposes, the aromatic diisocyanates, especially 2, 4-diisocyanotoluene (TDI), 1, 5-diisocyanonaphthalene, and 1, 4-diisocyanobenzene present interesting toxicologic properties. Although extremely inert in polymeric forms, and possessing a very low oral toxicity 1-8 g/kg,[2] these aromatic isocyanates, particularly the naphthalene derivative, are exceedingly irritating to the upper respiratory tract, producing histologic changes in animals at 0.09 ppm and death at 1 ppm upon repeated inhalation exposures. Man also responds at exceedingly low concentrations with evidences of allergic sensitivity such as asthma at air levels well below 1 ppm. Peculiarly sensitive individuals may show responses below 0.1 ppm, which is below the odor threshold of toluene diisocyanate for many individuals.

A level of 0.5 ppm of TDI produces throat irritation. The tentative threshold limit has been set for TDI at 0.1 ppm. In our present state of knowledge it is believed that the upper respiratory tract is first involved

following inhalation of low concentration of the isocyanates, pulmonary edema occurring only at far higher TDI concentrations. All evidence to date indicates no other type of systemic involvement from the isocyanates if the respiratory tract itself is free of involvement. Moisture greatly reduces the toxicity of 1, 4-diisocyanobenzene presumably by hydrolysis and destruction of the unsaturated conjugated system.

Three boron hydrides, diborane, pentaborane and decaborane have received considerable toxicologic and pharmacologic study.[3-6] Used as high-energy fuels these boranes are highly hazardous by all practical routes of entry into the body.

Diborane (B_2H_6), a gas at room temperature (b.p. −92.5C) differs from the others in toxicologic action in possessing no neurotoxic properties presumably because of its ease of hydrolysis; it is however, acutely, subacutely and chronically injurious to the lungs, producing congestion, edema and hemorrhage in higher doses and in the kidneys it leads to the production of tubular casts. The threshold limit of exposure has been tentatively set at 0.1 ppm; this is considerably below its odor threshold of from 2-4 ppm.

Pentaborane (B_5H_9) is the most hazardous of the three boranes. This liquid, (b.p. 58C) whose vapor in a two-hour exposure at 14 ppm results in immediate death of mice, at lower concentrations, produces symptoms of weakness and tremors indicative of central nervous system involvement but without the lung involvement seen with diborane. Cumulative effects are seen with low repeated doses. Skin absorption is a possible contribution to the over-all toxicity. On the basis of hazard from the vapor and its severely toxic effects, a tentative threshold limit has been set for this compound of 0.01 ppm. No medical preventive or therapeutic effective agent for this compound has yet been developed; complete protection is afforded by airline gas-masks or a mask cartridge layered with soda lime, silica gel and activated carbon.[7]

Decaborane ($B_{10}H_{14}$) presents a toxicity picture similar to, but slightly less than that of pentaborane but as it is a solid, it presents less of a hazard than pentaborane; accordingly its tentative threshold limit has been set at 0.05 ppm. The cardiovascular actions of decaborane in animals have been reported.[8]

It is recognized that the boranes are but additional examples of nonmetal hydrides such as phosphine, arsine, stibine, hydrogen sulfide, etc., which are characterized by their exquisite toxicity.

Although ozone is by no means a new compound, two factors have been shown to have remarkable effects on modifying its toxicity, exercise and pre-exposure. Exercise during exposure to ozone has been shown by the research work at Occupational Health Field Headquarters, U.S.P.H.S. to enhance markedly the toxic effects of ozone; simultaneous, intermittent exercise during a 6-hour exposure to otherwise non-injurious concentrations of ozone (around 1 ppm by vol.) proved lethal to rats and mice. On the other hand, pre-exposure to the same non-injurious levels of ozone, without exercise, resulted in a rapid development of tolerance to multilethal doses of ozone that persisted for at least four weeks. The tolerance which developed within 24 hours, protected the lungs from the pulmonary edema and hemorrhage common to lethal exposures but did not abolish the characteristic spasmodic breathing or the narcosis.

New Industrial Cancerigens

THERE is a tendency to belittle the carcinogenic potentiality of many substances on the basis that carcinogenicity in animals is no proof for carcinogenicity in man. It would seem a more reasonable view to regard all such compounds at least potentially carcinogenic in man.

Sufficient work on beryllium now seems to have been done in one laboratory (Saranac), at least, by Vorwald, Schepers and Scheel[9] to establish beryllium as a carcinogen in the rat. Inhalation of beryllium sulfate for several months (six) produced eventually what was interpreted as an adenocarcinoma of the lung. The cancer has been successfully transplanted subcutaneously in rats, whence it metastasized to the lung and the lymph nodes of the mediastinum. Inhalation of beryllium phosphor (13% Be) produced in three to six months lesions in the lungs which appeared to be squamous cell carcinoma. The beryllium cancer has not been produced by other workers although it is not rat-strain de-

pendent in the hands of the Saranac workers. Alkaline phosphatase inhibition appears to be the first step in the physiologic process leading to tissue changes. It is believed that the $Be(OH)^{+}$, a form through which all beryllium compounds pass in the fluids of the body, initiates the reaction. The lack of success of other workers elsewhere to reproduce beryllium cancer is still disturbing, however.

Doll[10] has found that the incidence of lung cancer among 105 English asbestos workers employed more than 20 years was tenfold that in the normal population. Cartier[11] studying over a nine-year period 4000 asbestos miners in Canada, involving 128 cases of asbestosis, 40 of them with autopsies, found six of these have bronchogenic carcinoma. Seven cases of lung cancer were found among asbestos miners with no asbestosis.

With such relatively small numbers of cases one must be extremely cautious in drawing the conclusion of a causal relationship between exposure and the disease. Snegireff and Lombard[12] several years ago pointed out in a study of lung cancer in arsenic plants involving similarly small numbers of cases that cancer deaths in any decade could have by chance been either far less than in the population as a whole or several times more than found in the plant. The question to resolve then in the asbestos exposures, is whether a 10-fold greater incidence of lung cancer is large enough to be significant when dealing with small samples of this sort. Before a final decision is reached it would seem well to wait until a more impressive number of cases has been documented. Moreover it seems to this author that the question of the nature of the asbestos in different localities and the associated minerals such as chromium and nickel, both recognized cancerigens, seem to have been too little considered. Asbestos is a fibrous form of several different species of minerals, a point commonly disregarded.

Hydrocarbon Products of Combustion

CARCINOGENIC hydrocarbons have now been shown to be present among the exhaust products of diesel and gasoline engines,[13] and in the air of English[14] and American cities.[15] These products have been shown furthermore to produce skin tumors in mice. Although these findings were made in connection with community air pollution studies, diesel and gasoline engines are used in many industrial operations. Efficient and innocuous operation of a diesel engine from an atmospheric pollution view has been pointed out as possible, moreover, without costly engine redesign.[13] The fact that human lung cancer has not yet been proven to arise from the inhalation of these hydrocarbon products should not act as a deterrent to an active program to reduce the air contamination of working areas from this source. Recent figures on lung and bronchial cancer from smokers and nonsmokers in urban (Liverpool) and rural areas[16] show definitely an urban "factor." The benzpyrene content of the air of urban areas was eight to 11 times greater than in the rural areas, a ratio which corresponds with the estimated mortality ratio among nonsmokers in those areas. Although the causal relation seems tenable, it should not be considered proven, as a considerable part of the evidence rests on the statements of the widows of the deceased as to their smoking habits.

Bladder and Skin Cancer

IT HAS NOW been repeatedly found that 4-amino diphenyl produces carcinoma of the urinary bladder of dogs fed this substance,[17-19] the last of these confirming reports being that of Deichmann in 1956. The cancer was predominantly squamous in type and was produced from total doses ranging from 30g (English workers) to 113g, 3 to 10 g/kg (American workers). The British investigators consider 4-amino diphenyl as a more effective bladder carcinogen than either benzidine or 2-acetyl aminofluorene, and at least as potent as beta naphthylamine.

A resurvey of the British chemical dye industry[20] produced statistical evidence that bladder tumors are associated with the manufacture of the dyes auramine or magenta, (aminodiphenyl and aminotriphenylmethane dyes (but do not necessarily arise from contact with the finished dyes themselves. Aniline, however, has been definitely excluded as a causative agent in bladder tumors, at least in the British chemical industry over the years 1910-1952.

Straight-run distillates[21] and higher boil-

ing point fractions of catalytically cracked petroleum[22] may contain numerous carcinogenic hydrocarbons. A relationship between exposure to these substances and high incidence of occupational skin diseases other than cancer has been reported[23] and tests in animals with cutting oils have implicated them as possible carcinogenic agents. More recently cutting oils with a sulfonated mineral-oil base have been connected definitely with squamous cell carcinoma of the skin among Canadian metal cutters.[24] Six cases of skin cancer and one case of papilloma have been reported among workers with an average exposure period of about 20 years. Although most of the lesions appeared on the forearms, one case involved the scrotum of a worker on whom oil splashed continually in the region of his lower abdomen, giving a clear definition to the relation between exposure and response from this type of oil. On the other hand, no skin cancer or precancerous manifestations have appeared to date among a group of 180 shale-oil workers in this country studied over a period of the past six years.[25] The group will remain under continued observation, however.

Toxic Thermal Decomposition Products

THE TOXICITY of the degradation products of a large number and variety of plastics, synthetic hydraulic and lubricating fluids and fire extinguishants has been determined chiefly by Treon and associates.[26] The importance of the studies is the finding that the over-all toxicity of the thermally degraded products from each substance was greater by a large factor than the substances from which they originated. The substances studied thus far include Teflon, Kel-F, Fluorolube FS, (all fluoro or fluorochloro-organic polymers), silicones, Gafite, (a chlorinated methacrylate), a paraffinic hydrocarbon lubricating oil, Skydrol, Pydraul F-9, Arochlor 1242, tricresyl phosphate, adipate and sebacate esters and Freon F13B1. In a few instances the toxic factors have been partly identified. As might be expected, the amount, nature and toxicity of the products was dependent upon the temperature of decomposition; in general, greater toxicity was experienced with increasing decomposition temperatures until a maximum was reached at a temperature characteristic of the substance. Temperatures above 500°F generally produced the more important amounts of toxic products from most polymers. The hazards of the decomposition products of the synthetic lubricants and hydraulic fluids are no greater than those from the common lubricating oils; a man would not stay voluntarily in the presence of significant concentrations of these products. Another interesting finding was a marked decrease in toxicity of the thermal decomposition products of Freon F13B1 in the presence of moisture. The mechanism by which this is brought about is being studied.

Trichloroethylene Exposure Problem

THERE is probably no industrial solvent on which there is currently more discussion on the proper level for worker exposure than trichloroethylene. Some indication of the lack of agreement may be seen in the widely different threshold limit values in use in America, (200 ppm); England, ICI (400 ppm); Russia (9 ppm); Italy, Parmegiani (100 ppm). Ahlmark and Friberg in Sweden, on the basis of trichloroacetic acid excretion values would prefer an average daily exposure to trichloroethylene of no more than 30 ppm.[27] Several possible reasons for these widely dissimilar values come to mind.

1. Trichloroethylene may contain appreciable and differing quantities of highly toxic impurities.
2. Differing methods used for sampling and analysis for trichloroethylene.
3. Differing means of appraising effects of exposure to trichloroethylene.
4. National idiosyncracies of dietary habits, metabolism, differing genetic origin and worker age groups.

The problem has importance that transcends that of the proper level for trichloroethylene; it involves also the more general question whether safe levels set for one country are appropriate for another in all instances. To date it is not possible to decide this definitely because, with the exception of Russia, most threshold limit values in use in foreign countries have been taken from values used in the United States. Only recently has a beginning been made in developing values in other countries. Because of the general importance of the question, efforts were made to elicit possible causes of

the difference from a number of foreign investigators familiar with trichloroethylene exposures.

The consensus of the foreign investigators, Ahlmark (Sweden), Truhaut (France), Grandjean (Switzerland) and Soucek (Czechoslovakia) in answer to the above four questions, was that neither impurities in the trichloroethylene nor faults in sampling and analysis of the air are believed to account for the differences. They believe rather that their more thorough medical evaluation, especially neurologic examination, tend to account for their appraisal of trichloroethylene as a more severe hazard to health than considered elsewhere. Answers to the more difficult fourth question of the role of national idiosyncracies were either not forthcoming or were admitted not to have been studied. The question may have an important bearing on the problem, however. Evidences of geography or national differences affecting metabolism of an industrial agent have been obtained from a comparison of vanadium ore workers in Peru and in America.[28]

Measurable changes in fingernail cystine occurred in Peruvian workers at urinary levels above 10μg/l whereas levels greater than 30μg/l were required before changes of similar magnitude were found among U. S. vanadium workers. In defense of the U. S. position of 200 ppm threshold limit for trichloroethylene may be cited the unbelievably low air values obtained by the European workers in the area of trichloroethylene degreasers (Grandjean),[29] the use of trichloroacetic acid as a means of evaluating safe exposure levels (Ahlmark)[27] and the lack of objective evidence in the U. S. of injury among trichloroethylene workers chronically exposed over a period of many years. Further exploration, both medical and toxicologic is needed to clarify this important question.

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HYGIENIC GUIDE SERIES

BERYLLIUM AND COMPOUNDS

I. Hygienic Standards

A. RECOMMENDED (TENTATIVE) MAXIMUM ATMOSPHERIC CONCENTRATION: Occupational 8-hour: 0.002 milligrams beryllium per cubic meter of air (mg/m³).[11,13] (This is also the current recommendation of the U. S. Atomic Energy Commission.) Occupational acute (less than 30 min.): 0.025 mg/m³.[7,8,11] Non-occupational 24-hour: 0.00001 mg/m³.[6]

(1) *Basis for Recommendation*: Animal experiments and observations of humans.

B. SEVERITY OF HAZARDS:

(1) *Health*: Extra hazardous for acute and chronic exposures, for all compounds, excepting beryl. Numerous deaths have occurred. Fluorides will, and other soluble compounds may, cause dermatitis and irritation of the nose, throat, and eye. Fumes and dusts of these compounds, as well as those of the oxide, hydroxide, and the metal may cause an acute pneumonitis[4] or, on longer exposure, a chronic disease, "beryllium poisoning." Latent periods in the disease's development, after exposure ceases, frequently occur. Although the respiratory system is chiefly affected, it is considered by some a systemic illness.[8] Non-occupational cases, caused by atmospheric pollution and contaminated worker's clothing have been reported.[3,6] The greatest concentration of chronic cases occurred in the manufacture of fluorescent lamps where the compound beryllium zinc manganese silicate, probably containing excess free or unbound beryllium oxide, was used. Granulomata, which respond only to surgical excision, may result from embedded particles in the skin. Beryl, and possibly certain other compounds, are apparently not harmful. Machining of beryllium-copper alloys has never produced illness. Pulmonary cancers in animals have been produced by inhalation experiments with pure beryllium oxide dust and beryllium sulfate mist.[10,15]

(2) *Fire*: None.

C. SHORT EXPOSURE TOLERANCE: No acute cases have occurred at levels below 0.025 mg/m³ for brief exposures. Above 0.1 mg/m³, cases of acute pneumonitis developed, with most individuals afflicted above 1 mg/m³.[7,8,11]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: 50 mg/m³ for six-hour daily exposure.[12]

II. Significant Properties

Properties are dependent on the specific compound.

III. Industrial Hygiene Practice

A. RECOGNITION: Exposures may occur in either the manufacture of neon signs, copper-beryllium alloys, or ceramics, in certain atomic energy processes, and in the extraction of beryllium from beryl ore. Most fluorescent lamp powders no longer contain beryllium, but some old bulbs containing it may still be in use.

B. EVALUATION OF EXPOSURE: Collection of atmospheric samples by filtration or by electric precipitation techniques, with subsequent analysis by photofluorimetry, using morin, or spectrographically.[1,14,16]

C. RECOMMENDED CONTROL PROCEDURES: Enclosed processes and local exhaust ventilation are required. Skin contact of soluble compounds, especially fluorides, should be prevented.

IV. Specific Procedures

A. FIRST AID: In acute inhalation exposures, call a physician at once.

B. BIOCHEMICAL ASSAY: Urine analysis may be done.[5,9] Positive results indicate exposure, but quantities cannot be correlated with the degree.

C. SPECIFIC MEDICAL PROCEDURES:[2,7]

(1) *Preplacement and periodic examinations*: Full size chest x-rays should be made on all personnel prior to job assignment. Periodic chest x-rays should be made at six-month intervals on potentially exposed personnel and removal from exposure should be prompt at the first abnormal finding. If accidental acute exposure occurs, chest x-rays should be made within a week.

(2) *Diagnosis of Chronic Delayed Beryllium Effect:* Many of the signs and symptoms resemble other diseases such as tuberculosis, sarcoidosis, and certain pneumoconioses. Diagnosis is difficult. Weight loss, chest x-ray changes, and positive tests for beryllium in urine and tissue are indicative.

(3) *Treatment*: Bed rest and oxygen are the methods of choice in acute cases. Usual symptoms are cough, shortness of breath, and chest x-ray changes. The treatment in chronic cases is symptomatic. In some instances, cortisone has been of value.

NOTE: DR. HARRIET L. HARDY (Massachusetts Institute of Technology) served as a consultant to the Hygienic Guides Committee in the preparation of this Guide.

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CARBON MONOXIDE

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 100 parts of gas per million parts of air, by volume (ppm).[2,3]

(1) *Basis for Recommendation*: Human experience.[4,8,13]

B. SEVERITY OF HAZARD:

(1) *Health*: Acute—moderate to severe; chronic—none. *No warning properties.* Severe acute poisoning may result in death or permanent damage. Severity of effects are markedly increased under conditions of reduced oxygen intake. Symptoms are typical of asphyxia.[15]

(2) *Fire*: Severe. Explosive limits are 12.5% to 74.2% by volume.

C. SHORT EXPOSURE TOLERANCE: 20% to 30% saturation in blood causes initial symptoms of poisoning. This will result from exposures of 1000 ppm for 30 minutes, or 500 ppm for one hour. 1500 ppm for one hour is hazardous to life. Short exposures (one hour or less) should not exceed 400 ppm, although acclimatization may reduce severity of symptoms.[4,5,6,8]

D. ATMOSPHERIC CONCENTRATIONS IMMEDIATELY HAZARDOUS TO LIFE: 3500 ppm immediately dangerous to life.[4,8]

II. Significant Properties

Colorless, odorless gas, generally produced by incomplete oxidation of organic or carbonaceous material. Frequently, but not invariably, accompanied by odor of unburned organic matter.

Chemical formula: CO

Molecular weight: 28

Relative density:	0.967 (air = 1)
At 25°C and 760 mm Hg,	
1 ppm	0.00115 mg/liter
1 mg/liter:	873 ppm

III. Industrial Hygiene Practice

A. RECOGNITION: Always present around fires and in exhaust gases of either coal or wood stoves, oil or gas burners, or internal combustion engines. Major industrial exposures occur in steel plants, mines, coke ovens, and illuminating gas manufacture or use. Usual symptoms, in order of increasing severity, are headache, drowsiness, nausea, unconsciousness, and death.

B. EVALUATION OF EXPOSURE:

(1) *Instrumentation*: Commercial devices are available for accurately determining low concentrations, using impregnated silica gel.[12] Continuous recorders and alarms are also available (Mine Safety Appliances Company, Pittsburgh) for monitoring carbon monoxide atmospheres.[10]

(2) *Chemical*: Passage of the atmosphere over iodine pentoxide, followed by determination of the liberated iodine.[1]

C. RECOMMENDED CONTROL PROCEDURES:

(1) Maintain all combustion devices at peak efficiency.

(2) Vent products of combustion to outdoors, and use supplemental general ventilation as required.

(3) Use Catalytic type mufflers on internal combustion engines operated indoors. Propane fueled engines are usually less productive of carbon monoxide than either gasoline or diesel fueled.

(4) Use tailpipe exhaust system in auto repair garages.

(5) Perform frequent atmospheric tests to assure the existence of unhazardous conditions.

IV. Specific Procedures

A. FIRST AID: In cases of asphyxiation, provide artificial resuscitation promptly, together with therapeutic oxygen (pure oxygen, if possible). Remove to fresh air, keep warm and prone.[8]

B. BIOCHEMICAL ASSAY: Blood saturation levels may be determined by the method of either Scholander[16] or Klendshoj,[11] by the Van Slyke gasometric method,[7] or by the pyrotannic acid method.[9,14]

C. SPECIAL MEDICAL PROCEDURES: Use of alcohol, narcotics, or barbiturates prior to poisoning may complicate treatment and should be recognized.[8] Measurement of CO saturation of blood is useful in determining degree of exposure.

V. Literature References

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HYDROGEN CYANIDE (HYDROCYANIC ACID, PRUSSIC ACID)

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 10 parts of gas per million parts of air, by volume (ppm):[1]

(1) *Basis for Recommendation*: Human and animal data.[5,6,9]

B. SEVERITY OF HAZARD:

(1) *Health*: Extra hazardous for acute; nil, for chronic exposures. Toxic action believed to be the result of enzyme inhibition on cellular metabolism. *Readily absorbed through the skin.* Odor response

varies widely, and olfactory fatigue readily occurs. Liquid HCN may be a skin and eye irritant. Little latitude exists between safe and dangerous concentrations.

(2) *Fire*: Severe fire and explosion hazard. Flash point, 0°C (32°F.) (closed cup). Explosive limits, 5.6% to 40% by volume.

C. SHORT EXPOSURE TOLERANCE: 50-60 ppm safe for one hour.[4]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: 3000 ppm, rapidly fatal.[4]

II. Significant Properties

Formed by reaction between acids and most cyanide salts. The normal content of carbon dioxide in the air may release toxic concentrations from salts and solutions.

Chemical formula:	HCN
Molecular weight:	27.03
Specific gravity:	0.697 at 20/4°C
Boiling point:	26°C
Relative vapor density:	0.93 (air = 1)
Vapor pressure: At 25°C. and 760 mm Hg,	546 mm Hg at 18°C
1 ppm:	0.0011 mg/liter
1 mg/liter:	906 ppm
Solubility:	Infinitely soluble in water, alcohol, ether
Odor:	Bitter almonds; threshold about 1 ppm by trained personnel.

III: Industrial Hygiene Practice

A. RECOGNITION: Hydrogen cyanide is used as a fumigant and as a basic compound in the synthetic chemical industry. Other sources of exposure occur in the plating, gold and silver ore extraction, photographic, dyeing, insecticidal manufacturing, and steel heat treating processes.

B. EVALUATION OF EXPOSURES:

(1) *Instrumentation*: Direct determination by the M.S.A. Hydrocyanic Acid Gas Detector (Mine Safety Appliances Co., Pittsburgh) or the Dräger Gas Detector (Drägerwerk, Lübeck, Germany). Neither of these are specific for HCN.

(2) *Chemical*: Collect in an all-glass device, using a trisodium phosphate solution containing phenolphthalin and copper sulfate.[8,10]

C. RECOMMENDED CONTROL PROCEDURES:

(1) Train all personnel in the recognition of the odor of hydrogen cyanide, in artificial respiration, and in the use of amyl nitrite.

(2) Prevent contact of cyanides with acids.

(3) All containers of cyanide salts and solutions, when not in use, should be closed, or provided with hoods and mechanical exhaust ventilation.

(4) Where hydrogen cyanide or its salts are used, provide mechanical exhaust ventilation, with special provisions for a high rate during emergencies.

(5) Impervious protective clothing should be worn when danger of skin contact exists.

(6) Provide emergency showers and eye washing fountains.

(7) Provide kits containing equipment for amyl nitrite, and sodium nitrite-sodium thiosulfate administrations,[11] in suitable locations.

IV. Specific Procedures

A. FIRST AID:

(1) Remove the individual as rapidly as possible to an uncontaminated area, by adequately protected personnel.

(2) Perform the following in the order of priority given, but as nearly simultaneously as possible: (a) Administer artificial respiration if breathing has stopped. (b) Administer amyl nitrite inhalation (ampoules). (c) Remove clothing and bathe. (d) Call a physician.

B. BIOCHEMICAL ASSAY: None.

C. SPECIAL MEDICAL PROCEDURES:

(1) *Preplacement*: None, other than tests for ability to smell 50 ppm of HCN. Individuals unable to detect this level should not be employed.[7]

(2) *Treatment*: Amyl nitrite inhalations and sodium nitrite-sodium

thiosulfate injections should be used *promptly*.[3,11] All physicians with potential hydrogen cyanide cases should become thoroughly familiar with the procedure. Methylene blue should *not* be used.

NOTE: N. P. WHITE (Shell Chemical Company) served as a consultant to the Hygienic Guides Committee in the preparation of this Guide.

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ZINC OXIDE

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 15 milligrams of zinc oxide fume per cubic meter of air (mg/m³).[1]

(1) *Basis for Recommendation*: Human experiments[3,5] and experience in industry.[2]

B. SEVERITY OF HAZARDS:

(1) *Health*: Slight to moderate for both acute and chronic exposures. Excessive exposure to the freshly formed fume produces characteristic symptoms known as metal fume fever. "Brass chills," "zinc shakes," and "brass-founders ague" are other descriptive names for this disease. Only the freshly formed fume is especially potent, presumably because the flocculating characteristics of this compound prevent redispersion of particles small enough to be breathed deep into the lung. Duration of the illness is generally a matter of a few hours, with no after-effects. Immunity to the fumes is generally developed after a day or two of work but may be lost, after a few days without exposure.

(2) *Fire*: None.

C. SHORT EXPOSURE TOLERANCE: 56 mg/m³ may be breathed for 20 minutes without symptoms.[3]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: Unknown.

II. Significant Properties

A finely divided fluffy white powder with no distinguishable odor or taste.

Chemical formula:	ZnO
Molecular weight:	81.4
Specific gravity:	5.5
Boiling point:	Sublimes at 1800°C
Solubility:	In mineral acids and alkalies

III. Industrial Hygiene Practice

A. RECOGNITION: Zinc oxide is used extensively as a paint pigment, rubber compounding chemical, and pharmaceutical, but is only likely to occur in the toxic state as a freshly formed fume in zinc smelters, brass foundries and metal recovery plants where the metal is being melted. Zinc fumes are formed during the welding and brazing of galvanized metals. Influenza-like chills, followed by fever, occur two to eight hours after a heavy exposure and may last several hours. The victim feels debilitated but generally is able to go to work the next day.

B. EVALUATION OF EXPOSURE: Freshly formed fume may be sampled most conveniently with the electrostatic precipitator or an efficient filter. If zinc oxide constitutes the only major air contaminant, large air samples may be weighed directly. Small amounts of zinc may be determined chemically by the dithizone method,[4] or by polarographic techniques.

C. RECOMMENDED CONTROL PROCEDURES: Enclosure and natural or exhaust ventilation of furnaces, in which zinc and zinc-containing alloys are heated and melted, are the

principal means of controlling the escape of zinc oxide fumes. Special types of exhaust hoods may be required for welding or brazing galvanized materials, brass foundry pouring stations, etc.

IV. Specific Procedures

A. FIRST AID: Bed rest and aspirin afford some relief from chills and fever but do not alter the course of the disease.

B. BIOCHEMICAL ASSAY: None.

C. SPECIAL MEDICAL PROCEDURES (including preplacement): None.

NOTE: DR. PHILIP DRINKER (Harvard School of Public Health) assisted the Hygienic Guides Committee in the preparation of this Guide.

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ANHYDROUS AMMONIA

I. Hygienic Standards

A. RECOMMENDED MAXIMUM ATMOSPHERIC CONCENTRATION (8 hours): 100 parts of gas per million parts of air, by volume (ppm).[1]

(1) *Basis for Recommendation*: Control of irritation to eyes and respiratory tract of humans.

B. SEVERITY OF HAZARDS:

(1) *Health*: Moderate for both chronic and acute exposures. Effects are primarily irritation of mucous membranes and skin. Quickly dissolves on moist body surfaces and exerts a strong alkaline action on the tissue contacted. Dermal irritation occurs above 1% (10,000 ppm) if the skin is wet and chemical burns may occur rapidly in concentrations above 3%.

(2) *Fire*: Moderate. Explosive limits are 15.5% to 26.6% by volume.

C. SHORT EXPOSURE TOLERANCE: The odor threshold is approximately 50 ppm.[5] Irritation has been industrially experienced at 125 ppm,[2] although Fassett's experience indicates a level 200-400 ppm.[3] Experimentally, throat irritation was observed at approximately 400 ppm, and eye irritation at 700 ppm.[6]

D. ATMOSPHERIC CONCENTRATION IMMEDIATELY HAZARDOUS TO LIFE: 2500-6500 ppm is considered dangerous to life in 30 minutes.[6]

II. Significant Properties

Anhydrous Ammonia is a pungent, irritating, colorless gas.

Chemical formula:	NH_3
Molecular weight:	17
Boiling point:	-33.35°C
Vapor pressure:	2.3 atm. at 20°C
Relative density:	0.597 (air = 1)
Solubility:	Water: 90 gm/100 ml at 0°C Alcohol: 13.2 gm/100 ml at 20°C Soluble in ether and organic solvents.
Odor threshold:	0.037 mg/liter (53 ppm)[5]
At 25°C and 760 mm Hg,	
1 ppm of gas:	0.007 mg/liter
1 mg/liter of gas:	1438 ppm

III. Industrial Hygiene Practice

A. RECOGNITION: By its odor and irritating effects.[5] Major uses are in agriculture, refrigeration, petroleum refining, water purification, and in the manufacture of nitric acid, fertilizers, drugs and chemicals.

B. EVALUATION OF EXPOSURES:

(1) *Instrumentation*: Moist phenophthalein test paper turns from white to red immediately at 100 ppm, and in five seconds at 10 ppm. Moist litmus paper turns blue in one second at 100 ppm, and in 6.5 seconds at 10 ppm.[4]

(2) *Chemical*: Absorption in acid and determination by titration or Nessler's reagent.[2]

C. RECOMMENDED CONTROL PROCEDURES:

Maintain workroom exposures below 100 ppm. Process enclosure and/or ventilation may be required. Protection for eyes and respiratory tract is indicated for brief exposures to concentrations in excess of 100 ppm. Training in the use of such equipment is essential.

IV. Specific Procedures

A. FIRST AID: Removal to a non-contaminated location should be prompt. Summon medical assistance. Artificial respiration and administration of 100% oxygen may be required. Keep patient warm. Remove clothing and flush surface areas with copious amounts of water if skin contact has been severe. Treatment for eye contact should be preceded by prompt and prolonged (15 minutes minimum) irrigation with water. Medical procedures are largely supportive with careful attention to the possibilities of eye and pulmonary sequelae.

B. BIOCHEMICAL ASSAY: None.

C. SPECIAL MEDICAL PROCEDURES: In preplacement consider existing chronic respiratory conditions which might be aggravated by coughing.

V. Literature References

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Because of space limitations, it is impossible to list all methods of exposure evaluation. The selections have been made on the basis of current usage, reliability, and applicability to the usual industrial type of exposure. Any specific evaluation and/or control problem will involve professional judgment. This can best be done by professional industrial hygiene personnel.

Respiratory protective devices are commercially available. Their use, however, should be confined to emergency or intermittent exposures and not relied upon as primary means of hazard control.

A relative scale is used for rating the severity of hazards: nil, low, moderate, high, and extra hazardous.

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Hygienic Guides and Binders Available

INDIVIDUAL Hygienic Guides in loose-leaf form may be obtained from the American Industrial Hygiene Association, 14125 Prevost, Detroit 27, Michigan, at 25c each. Also available are flexible loose-leaf binders for the loose Hygienic Guide sheets. The binders have been especially designed to provide maximum protection and ease of handling of the Guides. They will be especially useful in keeping a permanent file. The binders are blue in color, with white lettering, and are fitted with ¾" rings. The price is $1.25. The Guides and the binders may be ordered on the blank on page 329.

◆ President's Page

AN OUTSTANDING technical journal for the dissemination of industrial hygiene information was an early dream of the founders of the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION. In line with this, the first Board of Directors arranged for an Industrial Hygiene Section in the journal, *Industrial Medicine*. Fifteen years later, June, 1946, our official publication, *AIHA Quarterly*, was born.

Since 1946, there has been a five-fold growth in the *Quarterly* and it is now the outstanding publication for industrial hygiene information. This accomplishment is a direct reflection of the efforts of the *Quarterly* staff and the Editorial Committee. Today, the early dream of our founders is well on its way to fulfillment. We have every reason to be proud of the *Quarterly* on its Tenth Anniversary.

The stature of a professional organization is measured largely by the extent communication is provided within the profession in the fields of research, professional experiences and general news. Thus, for a professional journal to serve its purpose, its growth must be commensurate with the growth of the organization itself. A special committee is now comprehensively re-examining our ASSOCIATION'S overall need in this respect. Further developments of major proportions can be confidently expected of our official publication. However, growth is accompanied by increased cost. This must be met primarily through increased circulation and advertising. The *Quarterly* staff and the Editorial Committee are doing a tremendous job but ultimately the future of our official publication rests with the entire membership of the ASSOCIATION. The report of the special committee pointing out ways in which the full membership can be of help will be covered in a future AIHA Newsletter.

Lester V. Cralley

♦ Selected Titles and Abstracts

—FROM FOREIGN EXCHANGE JOURNALS

THE FOLLOWING is a partial list of articles, by titles and authors, from journals received by the AMERICAN INDUSTRIAL HYGIENE ASSOCIATION since the June, 1956, issue of the QUARTERLY in exchange for copies of the QUARTERLY.

Additional information on any of the journals or articles may be obtained from: Carrol S. Weil, Senior Industrial Fellow, Mellon Institute of Industrial Research, 4400 Fifth Avenue, Pittsburgh 13, Pennsylvania.

I. ARHIV ZA HIGIJENU RADA (Jugoslavia). Vol. 6, No. 4 (1955).

Normal Values of Lead Concentration in Human Blood. V. B. Vouk, Kata Voloder, O. A. Weber and Ljerka Purec, pp. 277 to 287.

To evaluate normal quantities of lead in the blood, 95 healthy subjects (100 men and 95 women) were randomly selected from the local population of Zagreb. Results, using a monocolor dithizone method, were found to be log-normally distributed with mean values of 36 and 34 mg/100 ml for men and women respectively. The upper normal limit of lead in blood is stated to be 60 mg/100 ml.

Effect of Cobalt on Resistance to Hypoxia in Rats. Ines Wesley, pp. 289 to 294.

Toxic Methaemoglobinaemia Due to the Action of Nitrites. T. Beritic F. Valic, pp. 303 to 310.

Porphyrinuria in Lead Poisoning. D. Djuric, pp. 315 to 325.

Chemical and physical properties of porphyrines and their metabolism in the human body are briefly described. Biosynthesis of porphyrines, production of methaemoglobin, and the influence of lead on this process are discussed in more detail. A review is given of the literature concerning the determination of coproporphrine in urine as a method both for the detection of increased exposure to lead and early diagnosis of lead poisoning.

II. THE JOURNAL OF SCIENCE OF LABOUR (Japan). Vol. 32, No. 2 (1956).

Dermatosis and Anemia Observed on Workers Dealing with T.N.T. Sumiko Ishizu, pp. 103 to 108.

On the Phosphorus Necrosis of Jaw Bone in a Phosphorus Plant. Takashi Nomura, pp. 109 to 116.

Ten case histories are recorded. Further examination of workers revealed that those who were handling phosphorus were liable to show a decrease in the A/G ratio of serum.

Lesion of the Eye Caused by Maleic Anhydride. Shigeru Tanaka, pp. 117 to 126.

Studies on Occupational Deafness of Coalminers. Part 1. Noises in Coal Mines. Yoshimasa Taketomi, pp. 127 to 134.

Effects of Heavy Labor in High Temperature on Donaggio Reaction, Amount of Urobilinogen Discharge and Flicker Value. Seisuke Sato, pp. 135 to 144.

III. THE JOURNAL OF SCIENCE OF LABOUR (Japan). Vol. 32, No. 3 (1956).

The Three Cardinal Forms of X-Ray Findings in Silicosis (Report III). Harunori Asakawa, pp. 159 to 170.

Clinical and Experimental Studies of Influence of Sulphurous Acid Gas on the Electrocardiogram. Part I. First Report on the Electrocardiograms of Sulfur Processing Workers at Matsuo Mine. Seiki Naganuma, pp. 171 to 178.

A Study on the Abnormal Stain and Pigmentation of Ocular Conjunctives Among Aniline Dye Workers. Fumi Nishida, pp. 179 to 185.

IV. THE JOURNAL OF SCIENCE OF LABOUR (Japan). Vol. 32, No. 4 (1956).

Proceedings of Twenty-Ninth General Meeting of the Japanese Association of Industrial Medicine.

Investigations of the Amount of Neutral 17-Ketosteroids Excreted in the Urine of Female Cotton-Mill Workers. H. Maki and S. Yoshida.

On the Excretion of Acetone Bodies in Urine of Employees in a Steel Factory. S. Ogawa and E. Hazashi.

Investigations on Water-Metabolism, Blood, and Urine of Open-Hearth Workers of a Steel Plant. S. Shinjo.

Hematological Observations on Coal Miners. N. Arimatsu, T. Kawachi and S. Ishinishi.

A Screening Test by a Group Audiometer. A. Koizumi, M. Ashizawa and S. Kawamura.

Sampling of Mercury Vapor by a Midget-Impinger. O. Tada.

Estimation of Phenol in Air. T. Fukuyama and T. Sato.

Treatment of the Lead Poisoned with Ca-EDTA by Oral Administration. S. Nisino.

Investigations on Workers in a Manganese Mine. Report IV. Y. Suzuki, K. Nishiyama, M. Doi, Y. Matsuka, T. Ueda, and T. Ochi.

Investigations on the Effect of Intratracheal Injection of Dusts in Rats. T. Sano and H. Osanai.

V. THE JOURNAL OF SCIENCE OF LABOUR (Japan). Vol. 32, No. 5 (1956).

Studies on Dust Control. Report II. Hazardous Dust in Blast Cleaning. Toyohiko Miura, Kikuzi Kimura, Mituo Morioka and Yahatiro Matusita, pp. 351 to 360.

Tentative Standards of Noise Tolerance. Takeo Yamamoto, pp. 361 to 367.

On the Change of Blood Glutathione Level in Experimentally Lead-Poisoned Rabbits. Toshihiko Nagai, Tokuro Huse and Shigamitsu Saikawa, pp. 390 to 403.

✦ Book Review

ATMOSPHERIC POLLUTION—ITS ORIGINS AND PREVENTION: A. R. MEETHAM, D. Sc. Pergamon Press, London, 1956, pp. 302.

The second edition of this English text contains a broad treatment of the air pollution problem. It includes extensive discussions of the various natural and artificial industrial fuels and the industrial and domestic boilers and furnaces used for their combustion. Major emphasis is placed on smoke resulting from fuel combustion as the source and primary component of air pollution. Current methods of pollution measurement and results of recent British surveys of pollution distribution are reviewed. Cyclic variations as well as those caused by weather changes are discussed. The effects of pollution on human, plant and animal health and growth as well as resultant property damage are covered. Current pollution abatement technology, control legislation and enforcement methods practiced in England and the United States are discussed. Pollution resulting from nuclear fuel and power plants are briefly reviewed. Selective bibliographies are appended to each chapter. —ISAIAH GELLMAN

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